electronics today

(handwritten annotations across cover)
5 INFO 9 "ALPS" POTS 17 RECORDER 23 26 34 TIMER CIRC 37
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43 52 53 LATCH & SYNC UNIT 56 57 ERRORS
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THE ULTIMATE CONTROLLER

ETI CONCEPT

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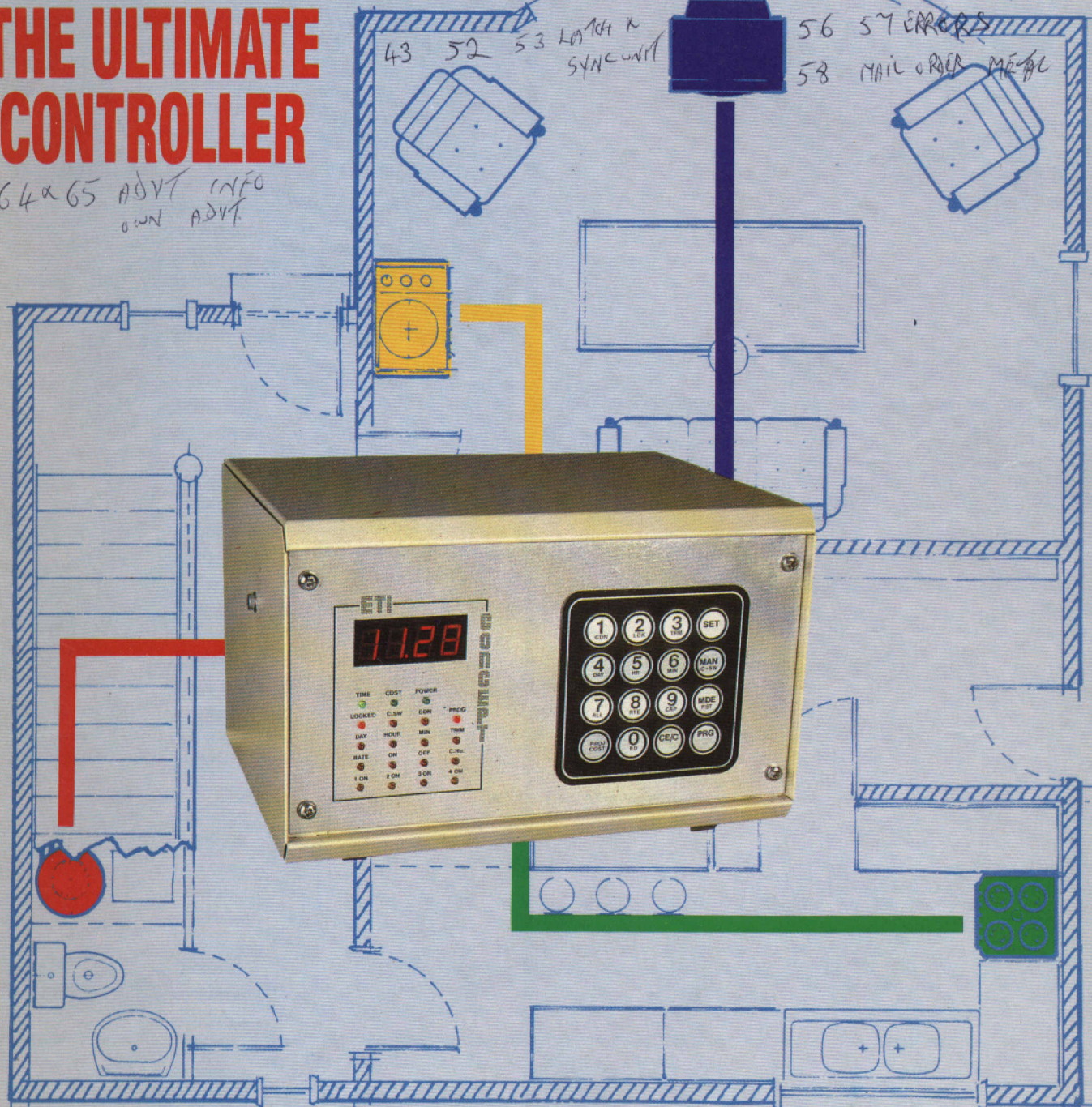
▶ HYPER-FUZZ—THE LAST WORD IN DISTORTION EFFECTS

▶ SWITCH MODE POWER SUPPLIES—DESIGNING FOR EFFICIENCY

▶ THE ETI EEG MONITOR—PUTTING YOUR BRAIN TO WORK

AUDIO....COMPUTING....MUSIC....RADIO....ROBOTICS....

FEATURES

PROJECTS

REGULARS

● No, the newsagent wasn't diddling you. The price of your favourite electronics magazine really has gone up to £1.40 this month. We are truly sorry about this but, as we are sure you will appreciate, our costs are always increasing and we can only respond by asking you to part with more of your hard-earned. However, we believe that ETI still represents the best value around and to prove it we're planning a really special issue for next month. Following the success of our Biofeedback Monitor project last year we'll be giving away another free PCB with the components to use on it following in the December issue. For details see page 6 — and keep on telling yourself that maybe £1.40 isn't so much after all!

● The newly-formed Test & Measurement Division of Feedback Instruments has published its first catalogue. In 12 colour pages it lists test equipment from such well-known names as Thandar, Hameg, Thorn-EMI, etc, as well as a range of own-brand equipment and it covers everything from multimeters, power supplies and oscilloscopes through to logic analysers and specialist equipment for fibre-optic testing. Copies are available from the Test & Measurement Division, Feedback Instruments Ltd, Park Road, Crowborough, East Sussex TN6 2QR. Tel: (08926) 3322.

● *Morel manufactures a range of loudspeaker drive units covering all parts of the audio spectrum. Of particular interest are the MDT and MDM ranges of soft-dome tweeters and mid-range units and the PP8 sub-woofer. This last item features two independent push-pull voice coils which can either be driven from a single source or fed separately from the two channels of a stereo system, providing a simple way to improve stereo bass response. For details contact Morel (UK) Ltd, 11 Foxtail Road, Ransomes Industrial Estate, Ipswich, Suffolk IP3 9RT. Tel: (0473) 719 212.*

● Those of you read our review of the Sage Audio amplifier modules (ETI May 1987) may be interested to learn that the MOSFET version of the modules is now on sale again. The price is £65 inclusive (as against £55 for the bipolar version) and you'll find all the details in Sage's advertisement in the classified section of this issue. Sage has also published a brief description of its dynamic class A biasing system in response to the recent correspondence on this subject in Read/Write. Copies are available from the address in the advert.

A Handier Digital Multimeter

Voltage and resistance can be measured quickly and easily using a new probe-type multimeter from TMK.

The Speedprobe is designed for single-handed operation and features a 3½ digit LCD display, full autoranging and finger-tip function selection. It measures up to 500V AC and DC and resistance to 20M ohms and incorporates a buzzer for audible continuity and diode testing.

A data hold facility allows testing in awkward places or in poor lighting conditions. Power comes from two 1.5V batteries giving approximately 80 hours of continuous operation and the complete instrument measures 161 x 37 x 19mm (6.34 x 1.46 x 0.75 in).

The Speedprobe costs £35.95 plus VAT and comes ready for use with a full guarantee.

Harris Electronics (London) Ltd, 138 Grays Inn Road, London WC1X 8AX. Tel: 01-837 7937.
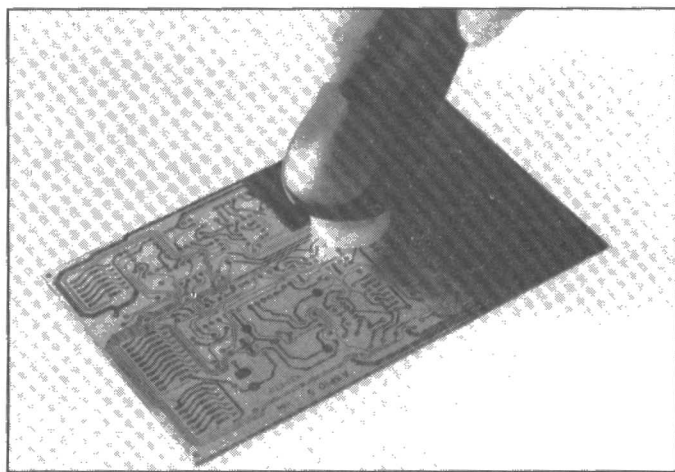
Cleaning Up On PCB Manufacture

The Seno Workstation from Mega Electronics enables anyone to make high quality printed circuit boards with a minimum of fuss and mess.

The workstation is based on the well-established Seno GS system which uses a two-compartment polythene bag to hold the etching chemicals. PCBs can be placed in the bag, etched and removed without spillage and with no need for the user to directly handle the chemicals.

Seno has added a new developer which does not employ sodium hydroxide and which comes in a handy wipe-over applicator. This removes the need

for developing tanks with the attendant risk of spillage. The applicator contains sufficient developer for 50-60 Eurocard-sized boards and replacements are available from Mega.

The Seno Workstation also includes film sheets, etch resist transfers and a grid for preparing PCB masters plus everything else needed to produce etched boards. It comes in a two-part moulded box which doubles as a work surface.

It costs £45 plus VAT and postage and can be obtained from Mega Electronics Ltd, 9 Radwinter Road, Saffron Walden, Essex CB11 3HU. Tel: (0799) 21918.

IT To Get Public Showcase

*P*lans are being laid for a new national exhibition centre designed to increase public understanding of information technology.

The centre will be known as the Information Age Project and will feature a permanent exhibition covering the history, present state and future development of computer technology. The aim will be to 'make technology come to life' and visitors will be encouraged to operate many of the exhibits and so experience information technology for themselves.

In order to encourage day-trippers the centre will be located in an attractive Thames-side setting in Berkshire complete with countryside park, nature reserve, shops and restaurants. The complex will also be used for trade shows and conferences and the facilities will include an auditorium, galleries, and a 200-bedroom hotel.

A charitable trust will be established to raise the £20m needed to build the centre, after which it is hoped that admission charges and the revenue from trade shows will cover running costs. Initial market research has indicated that more than 500,000 visitors can be expected each year.

The Dangers Of Cell Damage

We all know that lithium cells offer considerable advantages over other types of battery but are we sufficiently aware of the dangers?

A new 8-page leaflet from the Health & Safety Executive points out that lithium cells cannot simply be used as a direct replacement for other types of cell. They are easily damaged by short circuits and by forced discharge, and the results range from venting and release of hazardous substances through to outright explosion.

Non-rechargeable lithium cells can also be damaged by application of a charging current. This is a particular problem where batteries are used as a backup, and care must be taken to ensure that the main supply cannot reach the cells even under fault conditions.

The HSE booklet describes these risks in detail and goes on to provide guidance on selection, testing and use of lithium cells in various applications. It also includes advice on what to do in the event of an accident. The booklet carries the number ISBN 0 11 883947 0 and costs £2.50 from HMSO or through booksellers.

Superconductivity Takes Off

Research activity has grown rapidly following the recent discovery that zero-resistance electrical conduction can be achieved at far higher temperatures than was previously thought possible.

Ceramic components which are normally electrical insulators have been found to superconduct when cooled sufficiently, yet the temperature required to achieve this is well above the −254° previously required for superconductivity. Various companies (including Plessey, as reported in ETI News in August) have achieved superconductivity at temperatures around the −185° point, allowing cooling to be carried out using relatively inexpensive liquid nitrogen instead of the cumbersome and expensive liquid helium process.

Researchers have since reported superconductivity at temperatures as high as −175° and the race is now on to produce the phenomenon at room temperatures.

America and Japan are said to be at the forefront of research in this area and the governments of both countries have been quick to find additional funding. In Britain, the Department of Trade and Industry has set up a steering committee to co-ordinate superconductivity research, although as yet no additional government funds have been made available.

A research team at Birmingham University has produced Britain's first electronic device using a ceramic superconductor, a sensitive magnetic field detector known as a SQUID (super-conductor quantum interference device). SQUIDs are used in many applications, from submarine detectors to brain scanners. A team at Strathclyde University has produced a similar device and both groups expect to make further progress in this field. However, both say they are running into financial and manning problems.

In the industrial sector, a small research-based company called Basic Volume Limited has developed the world's first high temperature ceramic superconductor solenoid. The prototype is to be presented to the Science Museum and the company has since gone on to produce larger solenoid tubes and a range of other ceramic superconductor devices.

Basic Volume says it has achieved all this without outside funding but now needs financial support if the lead it has established is to be kept in this country.

Buzby Learns A New Language

People who cannot speak a word of one another's languages will soon be able to talk over the telephone using a new British Telecom invention.

The world's first instantaneous speech translation system, unveiled on August 5th can translate from English into German, French, Spanish, Swedish and Italian and BT is developing a more advanced model which will translate in the reverse direction or between any two of these languages.

BT is looking into the possibility of carrying out trials with another country.

The research laboratories at BT have been working on automatic computer translation since 1984.

As well as having a limited vocabulary the present system also has to be set-up to recognise the voice of each user. BT hopes that further development will remove this restriction and enlarge the vocabulary. It may be possible to produce more natural-sounding translated speech.

British Telecom PLC, Floor A3, 81 Newgate Street, London EC1A 7AJ. Tel: 01-726 4444.
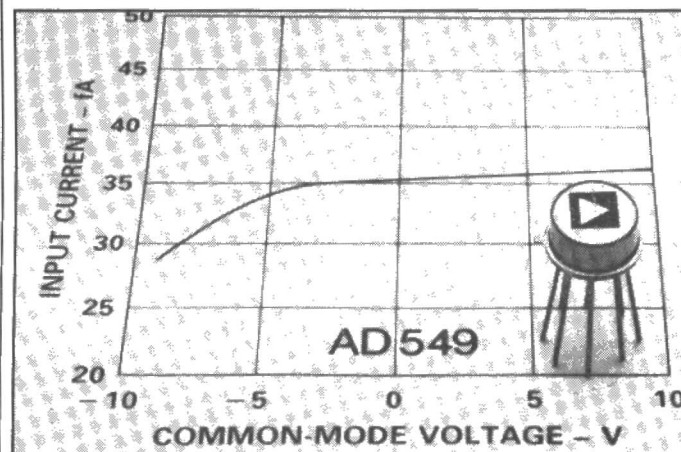
Op-Amp Input Reaches New Low

If you're not sure what a femto-amp is, now is the time to learn.

A femto-amp is 1×10^{-15} amps (in other words, one thousandth of a pico-amp) and a new op-amp from Analog Devices has an input bias current of just 60 of them.

The AD549 is intended for use in applications with source impedances of more than 1M0. It features a maximum offset voltage of 250µo, a drift rate of 5µV/°C, a minimum unity-gain band width

of 700kHz and a slew rate of 2V/µS.

The device is fabricated using isolated gate JFET technology and offers an input noise level of 4µV peak-to-peak and a maximum quiescent current consumption of 0.7mA. It is housed in a TO-99 package and comes in several versions, including one with full screening for military applications.

Analog Devices, Station Avenue, Walton-on-Thames, Surrey KT12 1PF. Tel: (0932) 232 222.

● **The British Standards Institution has issued two new papers on sound system testing. BS6840 Part 1 is entitled 'Methods for specifying and measuring general characteristics' and covers equipment marking, safety, etc. It partly supersedes the existing standard, BS5428 Part 1. BS6840 Part 13 has also been issued and covers loudspeaker listening tests. It specifies the size, acoustics and loudspeaker positioning in an 'average' living room and includes recommendations on programme material to be used during tests. Both papers are available from BSI Sales, Linford Wood, Milton Keynes MK14 6LE.**

● *Lambda Photometrics specialises in electro-optical products including fibres, lasers, optical signal amplifiers and attenuators and all types of electro-optical test and maintenance equipment. The range is described in a new, full-colour 30-page catalogue which is available free on request. Contact Lambda Photometrics Ltd, Lambda House, Batford Mill, Harpenden, Hertfordshire AL5 5BZ. Tel: (05827) 64334.*

● *Siemens Components is the title of an illustrated review published six times a year. The latest issue includes articles on power semiconductors, microwave power devices and optical signal transmission plus brief notes on new passive and active components and hints on using devices in practi ' circuits. For details of how to obtain Siemens Components contact Siemens Ltd, Siemens House, Windmill Road, Sunbury-on-Thames, Middlesex TW16 7HS. Tel: (09327) 85691.*

● **Greenweld has purchased a number of discontinued product lines from another distributor and says it will be selling them at less than half price. The stock includes plastic and metal cases, connectors, LEDs and tools and it is all described in a 16-page leaflet which is free on request. Contact Greenweld Electronic Components, 443 Millbrook Road, Southampton SO1 OHX. Tel: (0703) 772 501.**

● *AB Engineering has put together a fibre-optic toolkit which contains everything needed to strip and prepare fibre leads. Suitable for both single-mode and multi-mode fibres the kit is housed in a foam-lined carrying case and includes three different tools to remove the Kevlar protective sleeving and the primary and secondary coatings on optical fibres. Also included are the sleeve guides and bushes plus spare blades and screwdrivers. The toolkit is described in a data sheet available free-of-charge from AB Engineering Company, Timber Lane, Woburn, Milton Keynes MK17 9PL. Tel: (052525) 322.*
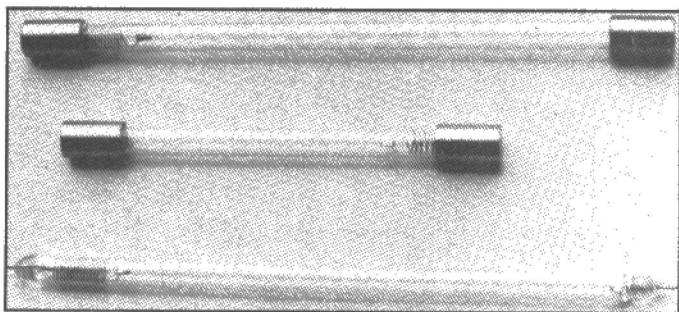
A Thinner Line In Lighting

For an unusual line in panel lighting, try one of the new thin line lamps from VCH Ltd.

Available in voltage ratings from three to ten volts, the lamps have straight filaments and can be supplied with either end-cap connections or wire leads. VCH expects them to find applications in electronic displays and read-out devices as well as in optical and photosensing equipment.

For details contact VCH Ltd, Beetons Way, Bury St. Edmonds, Suffolk IP32 6RA. Tel: (0284) 62411.

● 'Surface Mount Integrated Circuits' is the title of a new 28-page booklet from Analog Devices. It covers 46 data acquisition ICs now available in surface-mount plastic packages including op-amps, ADCs, DACs, V-to-F converters and many other devices. The booklet is free and can be obtained from Analog Devices, Station Avenue, Walton-on-Thames, Surrey KT12 1PF. Tel: (0932) 232 222.

● **A new data sheet from Colvern describes the company's range of precision conductive-plastic potentiometers. The four types available all use screen-printed conductive polymer tracks which can easily be altered to provide other values, resistance angles and resistance/rotation laws. For a copy of the data sheet contact Colvern, Crystalate Electronics Ltd, Spring Gardens, Romford, Essex RM7 9LP. Tel: (0708) 762 222.**

VHS Gets New Lease Of Life

The VHS video cassette standard seems certain to enjoy a rosy future following the launch of a new video recording system from JVC.

S-VHS offers higher picture quality compared with standard VHS but retains compatibility. The new tapes will not play on existing equipment but future S-VHS machines will be able to handle both the old and new formats, allowing users who already have a large collection of VHS tapes to upgrade without losing their investment.

S-VHS is said to offer almost double the picture quality of the standard VHS system. This has been achieved using a better tape formulation which can handle higher recorded frequencies. S-VHS carries luminance (black and white) information at frequencies between 5.4 and 7MHz compared with the 3.5 to 4.5MHz band used for standard VHS.

The enchanced picture quality should be obvious when recording present-day television broadcasts and playing back on a standard 625-line TV. However, the full benefits of the system will only become apparent when using high-quality pre-recorded tapes (or recordings made from future HDTV broadcasts) and a high-definition television receiver. JVC have plans to market a suitable receiver equipped with chrominance and luminance signal inputs, allowing a direct, high-quality link with the VCR.

The standard VHS format has already established itself as the most popular home video recording system, even though its picture quality is no better than that offered by the rival Betamax system and inferior to that of the ill-fated Philips V2000 system. Provided the S-VHS tapes and hardware are offered at competitive prices the technical improvement it offers, coupled with compatibility, should ensure VHS an even larger market share.

No date has been announced for the launch of S-VHS either here or abroad. It is likely that JVC will produce NTSC standard machines first for the Japanese and American markets before offering a version for use with the European PAL and SECAM systems.

JVC (UK) Ltd, Eldonwall Trading Estate, Staples Corner, 6-8 Priestley Way, London NW2 7AF. Tel: 01-450 3282.

Electro-West — September 8-9th
Bristol Exhibition Centre, Bristol. Described by the organisers as a market place and meeting point for everyone involved in the electronics industry in the South West. Contact Electro Exhibitions on (0273) 675 131.

Television By Numbers — September 11th
The IBA, London. See August '87 ETI or contact the BKSTS at the address below.

Television By Numbers — September 11th
The IBA, London. Seminar on digital television techniques. Covers the subject from first principles for the benefit of managers, analogue engineers and others unfamiliar with the technology. Contact the BKSTS at the address below.

Designing For Electromagnetic Compatibility — September 13-18th
University of Sussex. Vacation school. Contact the IEE at the address below.

7th International Display Research Conference — September 15-17th
The IEE, London. See July '87 ETI or contact the Institute of Physics on 01-235 6111.

Electronics In Engineering Design — September 15-18th
NEC, Birmingham. Exhibition and conference on mechanical/electronic systems interfacing. Contact Cahners at the address below.

Design Engineering Show — September 15-18th
NEC, Birmingham. See July '87 ETI or contact Cahners at the address below.

IDEX '87 — September 21-23rd
Metropole Exhibition Halls, Brighton. See April '87 ETI or contact Nutwood Exhibitions on (04848) 25891.

Semiconductor International — September 29-October 1st
NEC, Birmingham. See July '87 ETI or contact Cahners at the address below.

Internepcon — October 6-8th
Metropole Convention Centre, Brighton. See July '87 ETI or contact Cahners at the address below.

Digital Audio Post Production — October 11th
BAFTA, London. Training seminar organised by the BKSTS. Contact them at the address below.

Automotive Electronics — October 12-15th
The IEE, London. See July '87 ETI or contact the IEE.

Computer Graphics Exhibition and Conference — October 13-15th
Wembley Conference Centre, London. For details contact Online on 01-868 4466.

Conference For Young Engineers — October 16-18th
Strand Palace Hotel, London. See July '87 ETI or contact the IEE at the address below.

International Video & Communications Exhibitions — October 18-21st
Metropole Exhibition Centre, Brighton. See July '87 ETI or contact Peter Peregrinus Ltd at the IEE address below.

Radar '87 — October 19-21st
Kensington & Chelsea Town Hall, London. See July '87 ETI or contact the IEE at the address below.

Testmex '87 — October 20-22nd
Business Design Centre, London. See July '87 ETI or contact Network Events at the address below.

Reproduced Sound Conference — November 5-8th
Hydro Hotel, Windermere. Topics covered include acoustics, digital techniques, measurements and electro-acoustic music. Contact the Institute of Acoustics on 031-225 2143.

Electronic Displays — November 17-19th
Kensington Exhibition Centre, London. Contact Network Events at the address below.

Interact '87 — November 17-19th
Kensington Exhibition Centre, London. See June '87 ETI or contact Network Events at the address below.

Addresses:
British Kinematograph Sound and Television Society, 547-549 Victoria House, Vernon Place, London WC1B 4DJ. Tel: 01-242 8400.

Cahners Exhibitions Ltd, Chatsworth House, 59 London Road, Twickenham TW1 3SZ. Tel: 01-891 5051.

Institution of Electrical Engineers, Savoy Place, London WC2 0BL. Tel: 01-240 1871.

Network Events Ltd, Printers Mews, Market Hill, Buckingham MK18 1JX. Tel: (0280) 815 226.

READ/WRITE

Past Glories

Now that the MIDI Master Keyboard project has finished (August ETI) I should like to say how much I've enjoyed reading the articles and that I would very much like to see further projects along these lines in future issues of ETI.

I've made a start at building the keyboard and I will no doubt be in touch again when I run into problems!

John Shelve,
Rochford, Essex.

The MIDI Master Keyboard has proved to be a most popular ETI project. We shall continue to feature good music projects when suitable ones are submitted.

If any reader has produced a project of any type which they think is up to the standards of ETI we shall be most pleased to hear from them. Write in to the Editor and tell him all about it.

Corker

There I was, ambling through the letters page in the July issue when I come upon the amusing (ney, witty) little cartoon from Mr. (Mrs? Miss? Dr?) Cork. Good idea, I thought. So what have you done by August? Axed it!

Give us back our Cork, I say.
George Meldrum,
Mexborough, South Yorkshire.

Your wish is our command (on occasions, anyway!)

CORK

Another Remindalite?

Having seen the Remindalite project in the August ETI I was reminded of a circuit I've been using for four years continuously with 100% reliability and considerably fewer components — two diodes and a piezo sounder.

The point P is any part of the vehicle's wiring which is found by trial and error with a bulb or multimeter to be at 0V when the ignition is off and at 12V when the ignition is on.

W. H. Jarvis,
Ribchester, Lancs.

Where's the fun in that? No weeks of waiting for the components to come through the post, no up-to-your-eyeballs in solder and flux fumes. Are you trying to give electronics a bad name!

You do have a point, though. Your circuit is a teeny weeny bit simpler than the one published. However, what happens if you want to leave the side-lights on? The neighbours are going to get mighty annoyed at your car bleeping all night!

Alpine Inquiry

I would be grateful if you could tell me where I could obtain 'Alps' pots in small quantities.
A. Morgan-Richards
Nottingham.

Alps potentiometers are extremely good quality and are used in many commercial audio music designs. However, they are not widely stocked by electronics retailers.

Fortunately, Cirkit carries a range of pots from Alps. Prices range from 48p for single pots to 90p for stereo and £1.20 with a built-in switch. Cirkit is on (0992) 444111 and full details of the Alps range can be found in the Cirkit catalogue.

Top Of The Class

I am writing to say how very much I welcome the type of article which Paul Chappell has written for ETI recently.

Many electronics magazines have always given generous space to series of articles for beginners to the subject but after that there seems to have been a void which can only be properly filled by attendance at college classes.

Much of my learning has been the result of self-education which has often been inefficient and not neccessarily good because guidance has been lacking on the best books to read.

The Circuit Theory articles demand a little more from the reader than the assimilation of easy facts and ideas and help to take me that much further.
A. E. Wallwork,
Sutton Coldfield.

Basic O Level electronics does seem to be regurgitated with increasing regularity in some magazines and it is indeed the idea of the Circuit Theory series to go that step further and put a few basic theories to work in electronic design. We are glad you like it so far and hope the series continues to please as it develops.

As the Editor gets down to another day's hard READ/WRITE page preparation it starts to rain outside. It's July for pity's sake. It's meant to be sunny at this time of year. It's meant to be summer. We can't expect even ETI readers to alter the weather (but that is a good idea for a project . . .) but you can put a little sunshine back into his life with a missive or two. Drop ETI a line at:

Electronics Today International,
1 Golden Square,
London W1R 3AB.

ETI

DESIGNING FOR EFFICIENCY

Switch mode power supplies are becoming increasingly popular, largely thanks to developments which have made them smaller, more reliable and even more efficient than before. Les Sage looks at the theory behind SMPS operation and demolishes a few myths.

Until about ten years ago almost all the power supplies used in mains driven equipment were of the conventional (linear) type. The incoming AC would be stepped down (or in some cases up) by a transformer and then rectified, smoothed and if necessary stabilised to produce the required DC output voltage.

This system works well and has the advantage of simplicity but it also suffers from a number of drawbacks. The mains transformer must be comparatively large if it is to operate efficiently at the low mains frequency (50Hz in this country) and the smoothing capacitors must also be large so they can store charge for the long periods between cycle peaks.

Stabilising the output voltage presents problems too. The usual method is to set the smoothed transformer voltage rather higher than the required output voltage and then dissipate the excess as heat. This works well but is very inefficient and in large power supplies may demand lots of cooling.

The alternative is a switching power supply, in which the AC is rectified and smoothed directly to produce a DC voltage. This is then 'chopped' at high frequency using suitable switching devices driven from an oscillator. The resulting AC can be stepped down (or up) using a far smaller transformer than would be needed at 50Hz and the smoothing capacitors can also be quite small. Additionally, the output can be regulated simply by adjusting the duty cycle of ths switching waveform, a method which is simple to implement and very efficient.

Switch mode power supplies (SMPS) are, of course, used for DC-DC conversion as well as for AC-DC conversion and the principle is easily extended to produce dual-rail or multiple outputs from a single AC or DC input. Given their versatility, it is not surprising they are now used in such a wide range of applications and that so much effort is put into developing ever smaller, more efficient and more reliable units. The aim of this article is to describe the basic operation and the various types of SMPS and to cover in detail one of the most important and often least understood aspects of the overall design, the operation of the switching transistor.

Switching Myths

Most SMPS under 200W are single-ended using either the forward or flyback system. The switching characteristics of these circuits are similar so reference will be made only to the flyback type. Understanding the switching design problems associated with this circuit forms the basis for understanding all the other types. First let's dispel some of the myths surrounding SMPS.

Fig. 1 Power dissipation (Pd) in a transistor switching a resistive load.
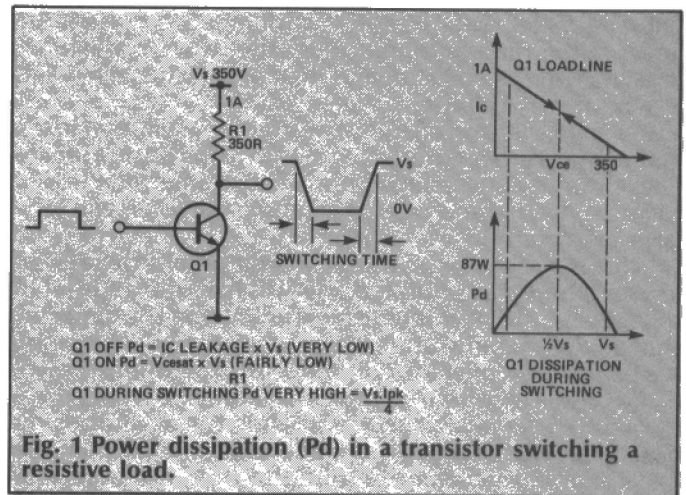
The transistor is simply a switch which is either on or off and its dissipation is low in either state (Fig.1). It is often thought that, provided the transistor switches both ON and OFF very fast, the power dissipated during switching will be small. However, this is only true for a transistor with a *resistive* load as in Fig.1.

In a SMPS the load is almost a pure inductor and the current and applied voltage are out of phase by nearly 90°. If the voltage and current around the transistor are analysed separately with respect to time, we find that during switch on the dissipation is extremely low and during switch off the dissipation is extremely high.

The basic principle of the flyback converter is to convert the rectified mains DC into a high frequency squarewave drive which is then transformed up or down to the required output potential. At the same time the circuit must provide galvanic mains isolation. Most circuits have feedback regulation using an opto-coupler or an additional winding on the transformer.

Regulation is achieved by comparing the output voltage with a reference voltage. The output of the comparator controls the-on time of the chopper transistor to provide regulation. This action also smooths out the 100Hz ripple from the mains side which would normally be transformed along with the high frequency to the output, thus allowing smaller values of smoothing capacitors to be used whilst still obtaining low output ripple.

It can be seen straight away that this forms a closed loop negative feedback system with the transformer in the feedback loop. With high loop gain, any alteration to the transformer turns ratio will have very little or no

effect upon the output voltage since any change within the loop will be corrected by the negative feedback.

It is theoretically possible to have more turns on the secondary than on the primary and still have an overall step-down without loss of efficiency. In practice there is an optimum turns ratio for any given design which balances transistor VCEmax, minimum on time and loop control range, etc, but this is not in a direct ratio of the input to output volts as in a conventional transformer.

The Switching Cycle

It is easiest to analyse the system as if it were already running rather than to analyse it from start up.

Starting with the beginning of the cycle where the transistor is off, the base is first driven on by a positive current and the collector potential falls rapidly to ground. This is shown in the load line drawing (Fig. 4) where it is represented by the line between A and B.

Although the transistor is now fully on, no power is being dissipated because the current is not flowing yet. Current will start to flow once the transistor has reached saturation but instead of rising immediately to its final value it will increase steadily with time. The rise will be linear rather than exponential because there is very little resistance in the collector and the time constant (T = L/R) will be nearly infinite.

As the collector current rises, energy will be stored in the transformer core as $E = \frac{1}{2}L\,IX^2$. This is the forward phase of the conversion. After a short time the current will have risen to several amps and the transistor will then have to switch off.

This is probably the most difficult part of the design to get right. Q1 is saturated and will have a high level of base charge storage. It is also essential that the collector voltage rises rapidly but Miller capacitance between the base and the collector will tend to slow things down.

For this reason an enormous amount of base drive is required to switch the transistor off as quickly as possible. This is normally several times greater than the maximum base current required to hold the transistor in saturation in the first place. Figure 5 shows the base drive waveform which takes the transistor's base hard negative with respect to its emitter. This large negative voltage also helps to maximise the Vce breakdown rating of the transistor (Vcex) and can double it from, say, 450V to nearly 900V.

Since the transformer is virtually a pure inductor, any attempt to reduce the current flowing by switching off the transistor is violently resisted according to Lenz's law. A very large back EMF will be generated proportional to the rate of change of current EMF = −L dI/t. As we wish to switch the transistor off as fast as possible the back EMF will be extremely high, taking the transistor collector as much as several thousand volts positive instantly. The magnitude of this back EMF is actually determined by the total energy stored in the core ($\frac{1}{2} LI^2$) dumped into the total stray capacitance of the transformer windings, etc, and stored as $\frac{1}{2} CV^2$.

Power transistors are very slow devices to commutate current flow and it usually takes several micro seconds for the collector current to fall to zero due to storage. Since there is now a very high voltage across the device and a very high current still flowing the dissipation will also be very high, typically over 1000W instantaneously. If the transistor is too slow in turning off it will then enter the second breakdown region, the current increasing again to eventual destruction.

At this point the designer has two choices. The first is to design for an even larger reverse bias turn off potential, perhaps taking the transistor's base so far into the reverse bias region that the base starts conducting again in reverse. This increases the breakdown voltage beyond twice the Vceo, an example being the common
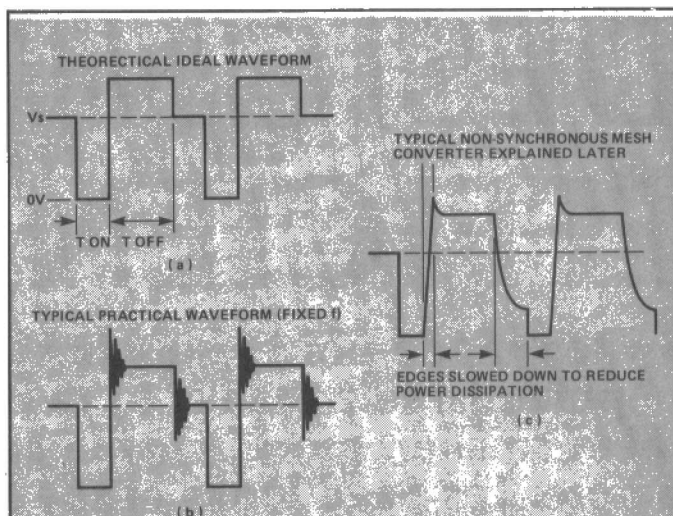

Fig. 2 Typical voltage waveforms at the collector of the switching transistor in a flyback SMPS.
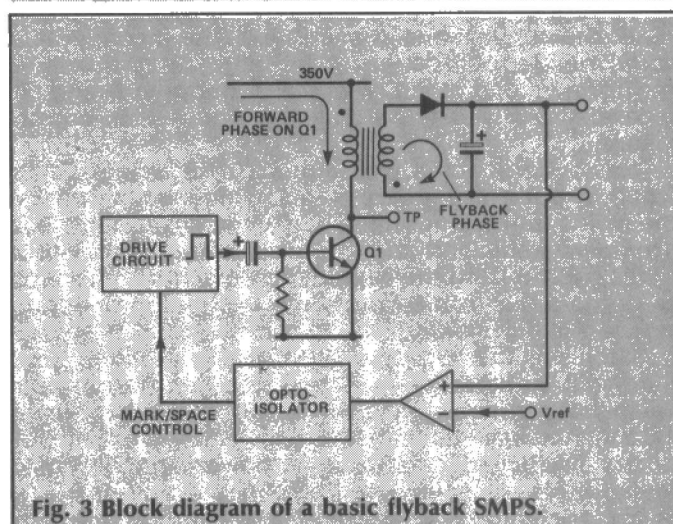

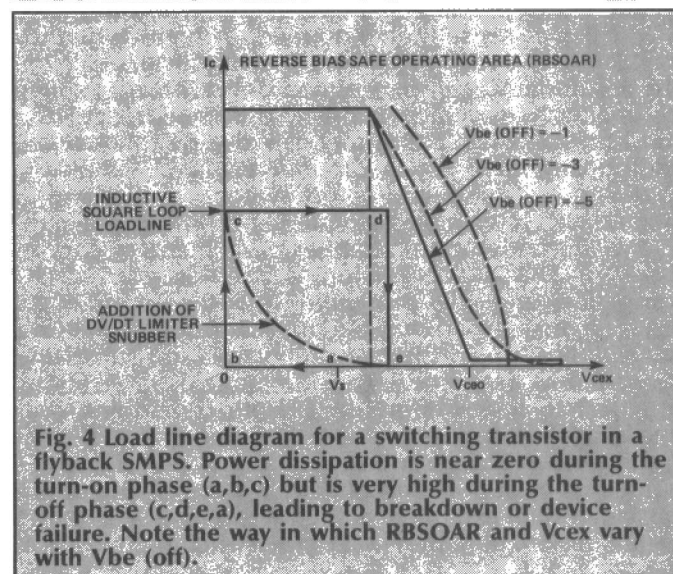Fig. 3 Block diagram of a basic flyback SMPS.

Fig. 4 Load line diagram for a switching transistor in a flyback SMPS. Power dissipation is near zero during the turn-on phase (a,b,c) but is very high during the turn-off phase (c,d,e,a), leading to breakdown or device failure. Note the way in which RBSOAR and Vcex vary with Vbe (off).

TV line output stage with typical flyback voltages of 1200V. The snag with this method is that the reverse base bias reduces the reverse bias safe operating area (RBSOAR) energy dump capabilities. Should the Vcex still be exceeded, second breakdown failure will be even more likely.

The second choice is to limit the reverse base-emitter potential to less than 1V, perhaps by using an anti-parallel

diode. This reduces the Vce breakdown voltage but with less reverse base potential the transistor has a better chance of surviving a breakdown without any secondary failure mode. Some transistors are designed for this particular feature and are able to withstand what is termed an inductive load energy dump, rated in mJ. They are used, for example, in hammer drivers which have to have a fast return stroke and use breakdown energy dumping on every cycle.

As we are actually designing a power supply, we wish to transfer all the input power to the output without transistor breakdown energy dumping. A secondary winding on the transformer with an output rectifier clamps the rising collector potential to Vo times the turns ratio. This is called V extension as it allows the transistor Vce to extend above the supply by Vex.

As the transistor switches off (flyback) and the collector swings positive above Vsupply, then at Vex the output rectifier will conduct charging the output capacitor and so supplying load power. The collector current has by now returned to zero, from d to e, and all the energy stored in the core is discharged linearly into the load. With zero energy in the core the collector potential must return to Vs and one cycle is complete.

The most important point about this complete cycle is that zero energy must remain within the core at the beginning and end of each cycle. Any residual energy left will leave a net core flux offset resulting in possible saturation the following cycle. Therefore the total area ab,bc (forward phase) must be made equal to the total area of the flyback phase. To guarantee this factor the transistor must not switch on before the transformer flux has returned to zero under worse case conditions of low mains and high load. This explains why the waveform in Fig. 2 has this step and is not a squarewave, since simple squarewave drive at a fixed frequency would not necessarily switch the transistor on exactly at the same point for various loads.

In fixed frequency (synchronous converters) the on-time is under control of the feedback loop such that for an increase in load on-time increases to store more energy in the core. With more energy to transfer to the output the power transfer time must also increase. This means that the regulation time reduces.

Practical Problems

To return to the earlier mention of transistor off drive and RBSOAR, the most common way of overcoming the instantaneous rise in potential at switch-off is to place a snubber capacitor across the transistor's collector and emitter. This is often found in thyristor circuits as thyristors have a habit of switching on with fast dv/dt changes. This capacitor forms a resonant circuit with the transformer inductance, the first quarter cycle acting as a dv/dt limiter allowing time for the collector current to reduce to a safe value. Typical values are 1n5 at 1k5V for a 1.7mH transformer. This resonates at around 100kHz giving a first quarter cycle dv/dt delay of around 2–3µs. These are typical values for a 150W 25kHz SMPS.

In practice it is mandatory to include this capacitor otherwise repeated inductor energy dumping causes eventual failure. Some simple circuits include zeners across the collector and emitter. These do not actually limit Vce dv/dt but just clip any peaks, dissipating power in the process. Examples include battery inverters and capacitor discharge ignition circuits. Random secondary breakdown of the active devices is quite common.

The problem now is that at the point of transistor turn on, all the energy stored in this capacitor must be dissipated in the transistor. This is wasted power, so including the capacitor is simply a means of trading overall efficiency for greater reliability.

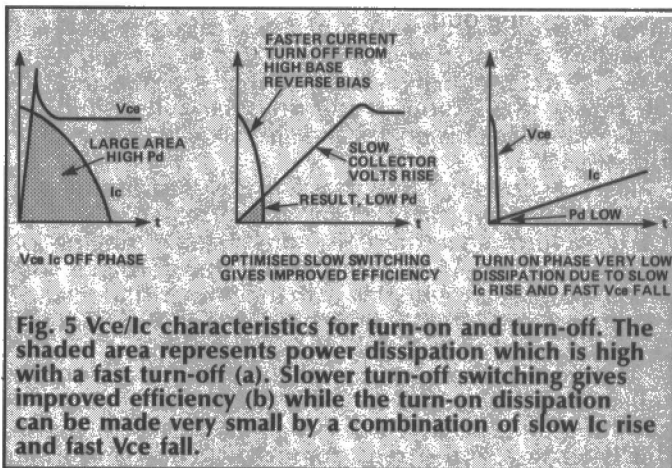At the point of transistor switch on there will be near

Fig. 5 Vce/Ic characteristics for turn-on and turn-off. The shaded area represents power dissipation which is high with a fast turn-off (a). Slower turn-off switching gives improved efficiency (b) while the turn-on dissipation can be made very small by a combination of slow Ic rise and fast Vce fall.
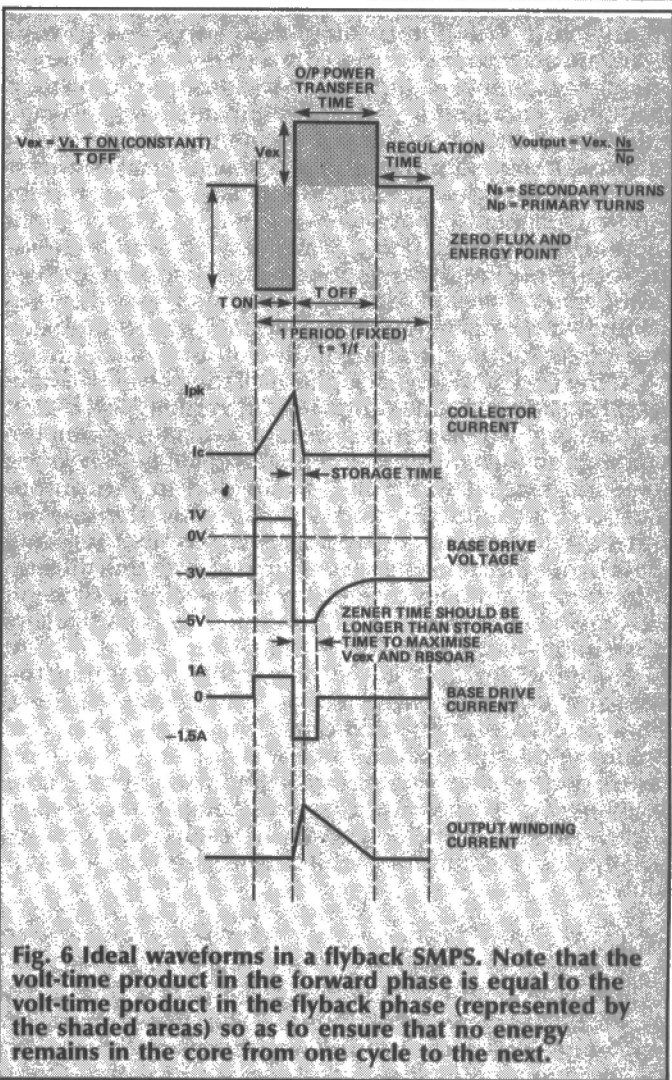

Fig. 6 Ideal waveforms in a flyback SMPS. Note that the volt-time product in the forward phase is equal to the volt-time product in the flyback phase (represented by the shaded areas) so as to ensure that no energy remains in the core from one cycle to the next.

infinite collector current flowing to discharge the capacitor, so there is now an even greater reason to slow down the turn on time of the transistor. Contrary to popular belief, slowing down the switch-on does not increase the transistor's dissipation since transformer primary current has not yet started to flow (Fig. 4 points a to b). As the capacitor must be discharged fully on each cycle all the energy stored in the capacitor will be dissipated as heat in the transistor regardless of the length of time the transistor takes to turn on.

Slowing down the turn-on will however limit the instantaneous peak current to a safe level. This is achieved simply with a small base resistance of a few ohms or an inductor, which will act as a crude current

limiter since the transistor's hFE falls off rapidly at high collector currents. Slowing down the turn-on also helps to reduce RFI problems and, as we shall see later, reduces the power dissipation in the drive circuit, helping to further improve efficiencies and also allowing direct drive from an IC.

Fig. 2a shows the now familiar ideal waveform, and Fig. 2b shows a typical practical waveform. We see on the real waveform that there is considerable ringing on switching edges. This is due to the transformer's stray winding capacitance ringing with the primary inductance. The first ring occurs at transistor switch off and has been designed in as a dv/dt delay as explained.

We only wanted a quarter cycle ring as the initial dv/dt limiter but in practice it is very difficult to stop the transformer inductance from ringing over several cycles. This is because, as the transistor turns off, the transformer inductance is no longer heavily damped but left virtually open circuit. The output rectifier is supposed to have switched on to transfer the core energy to the output, but these take several hundred nano seconds to turn-on and this, combined with the transformer's leakage inductance, allows for several cycles of ringing.

Using a large value of snubber capacitor can suppress the ringing by lowering its frequency and the transformer can be designed to have low leakage inductance (tight coupling between windings), all allowing more time for the rectifier to conduct. As soon as this happens, energy will be transferred to the load and this loading will ensure that the transformer is again heavily damped, suppressing the ringing for the duration of the output flyback phase.

At the end of the flyback phase all the power will have been transferred to the output and no energy will be left in the core. There cannot be any voltage across the windings so the collector potential will fall to Vs. We see a second ring at this point, again due to the output rectifiers turning off and leaving the transformer undamped. Residual energy stored in the winding capacitance and snubber now ring with the transformer inductance, eventually dying away but wasting power and creating RFI in the process. This output ring is particularly undesirable and can result in transistor failure.

The problem now is that it is quite likely that the transistor could be switched on during one of these ringing peaks, placing additional stress upon the device and lowering efficiency. If the transistor were driven on earlier, before the ringing and before complete core discharge (as is often the case with simple squarewave drive) an increased inefficiency again results coupled with possible core saturation which can lead to transistor failure.

Regulatory Control

Since the amount of energy stored per cycle is equal to $E = \frac{1}{2} LiW$, varying the on time will vary the energy level which under loop control will exactly match the output energy required. If a larger load is placed on the output the feedback loop will cause the on time to increase, storing more energy in the core. More energy will cause a longer core discharge time and hence the rule of equal areas still holds.

This brings us to a very important aspect of the flyback converter. Since Vo is regulated and so is constant, Vex is related to Vo times the turns ratio, so Vex is also fixed under feedback regulatory control. It is this that allows us to theoretically have say a 1:1 turns ratio but with 12V output from a supply of 350V. This would give a Vex also of 12V, and the resulting mark-to-space ratio of the switching waveform to maintain equal in/out areas would now be 350 x on-time = 12 x off-time or 1:29.

This is inefficient in terms of switching times and saturation power losses since the transistor's collector
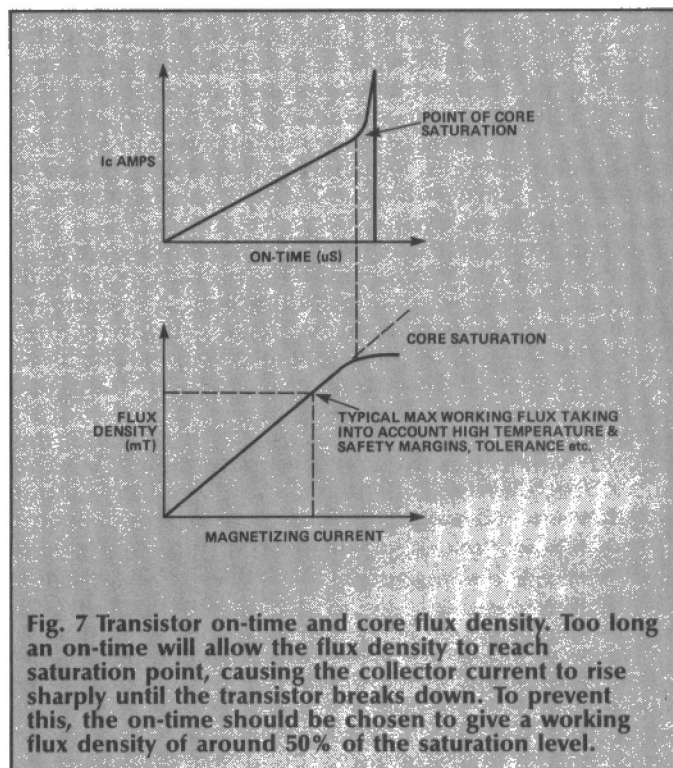
Fig. 7 Transistor on-time and core flux density. Too long an on-time will allow the flux density to reach saturation point, causing the collector current to rise sharply until the transistor breaks down. To prevent this, the on-time should be chosen to give a working flux density of around 50% of the saturation level.

current must be very high to charge the core in such a short time. It also does not allow much room for loop control given that the minimum mark-to-space ratio (M/S) allowed is equal to the snubber ringing frequency. Its only advantage is that the maximum ideal Vce rating for the transistor would only need to be Vsupply plus Vex or 363V (ignoring additional safety margins).

Similarly for line variations, with a lower line supply input the feedback control loop will increase the on-time to maintain the same level of energy transfer. In practice a suitable transistor is chosen, bearing in mind that higher voltage transistors have higher saturation losses. Therefore the parameters of Vcex, Vex, ICpk, M/S and turns ratio are all interrelated and form part of a complete design package.

The variable parameters Vex, turns ratio, etc, are generally based around standard off-line switching transistors available. A computer programmed with these relationships speeds up the design as the parameters of given transistors can be entered in and the computer then calculates the optimum transformer turns ratio to make maximum use of the transistor chosen. This shows that the transformer is not designed for input/output volts and current ratio but on the transistor ratings.

There is a limit to the maximum M/S ratio allowed and this is 1:1. Above this there would be insufficient off time for the transformer flux to reset fully, thereby resulting in a net magnetic offset leading to possible core saturation and failure. A typical nominal M/S would be 1/1.3 but as explained this is not mandatory so long as the maximum M/S under loop control does not exceed 1:1. This problem can be solved but generally results in poorer efficiency and the very high potential developed between windings makes it difficult to wind a transformer with adequate insulation.

The second article in this series will deal in more detail with each of the problems mentioned here and show how recent developments have overcome these problems and turned some of them into advantages. This leads on to a description of the latest non-synchronous 'Mesh' converter system which use a variable frequency rather than a fixed frequency and zero energy switching to achieve even greater efficiency and reliability.

ETI

CIRCUIT THEORY

Paul Chappell sets phasors to stun and attacks sine wave representations without mercy.

This month we're back with sine waves again and I'm trying out a variation on the August article's theme of simplifying information and getting it into a form which brings out the essentials and gets rid of irrelevant detail.

There are a number of ways of representing a sine wave. Figure 1 shows two possibilities. The first is the usual graphical representation. A diagram like this gives a good deal of information about the wave — its shape, amplitude, frequency and phase at the chosen starting point. Just about all you could ever want to know about it!

Figure 1b shows a more abstract representation of the same wave. The frequency is shown by the position of the line along the horizontal scale and amplitude is given by the height of the line. This diagram is more concise than Fig. 1a (and takes less drawing skill!) but some of the information is lost. The shape of the wave is not shown, so to interpret the diagram you have to know what a sine wave looks like. Another loss is phase information. There's also a slightly less obvious loss — see if you can spot it. (Look for a way to alter Fig.1a to give another wave which would have the same representation in Fig.1b).

The loss of phase information means that if two or more sine waves are shown on the same diagram, it is impossible to say exactly what time domain waveform they represent. Fig.2a may represent either Fig.2b or Fig.2c or something else entirely. Without knowing the relative phases of the two sine waves, there is no way to decide. (Strictly speaking it makes no sense to speak of the phase difference between two waves of different frequencies since it changes at every instant. What you can do is to compare each component with a sine or cosine of its own frequency *at a particular instant in time* which will give enough information to decide the time relationship of the two waves.

For example, if both waves were exactly in phase with the sine of their own frequency at some instant in time, Fig.2c would be the correct time domain waveform. On the same pedantic note, I'd better explain that I'm using the phrase 'sine wave' to mean 'any wave which is sinusoidal in shape', and unadorned 'sine' and 'cosine' to mean waves that 'begin' at 0 and 1 respectively at some instant t=0. Phase relationships are God-awful things to talk about without sounding too text-booky and I don't want to confuse you in my attempts to do so!

In many situations the frequency spectrum of a wave form is the most important characteristic. An example is frequency interlacing in colour TV systems. The frequency spectrum of a monochrome TV signal has the strongest frequency components at multiples of the line frequency with smaller components at multiples of the field frequency on either side. Figure 3a is an idealised diagram of a portion of this spectrum. The gaps in the spectrum allow a rather cunning trick to reduce the bandwidth needed for colour TV transmission. Instead of avoiding interference by putting the colour sub-carrier at some frequency way above the monochrome information, it can be slotted in to fill up the gaps!

Suppose the colour sub-carrier frequency was chosen to be 200.5 times the line frequency. The main additional
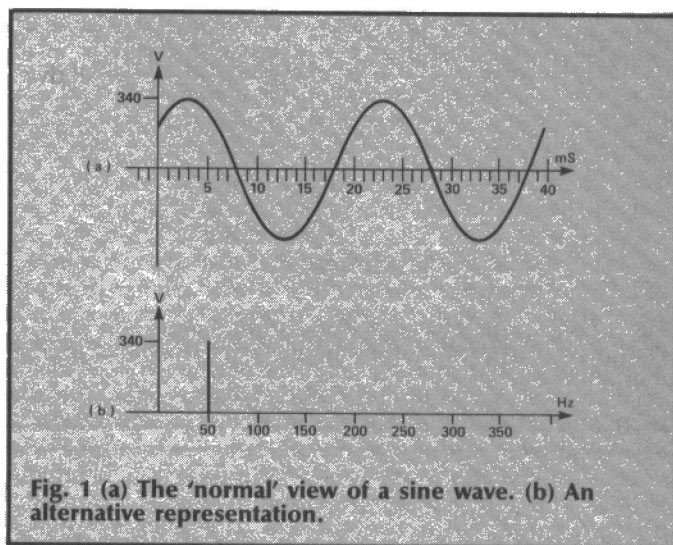
Fig. 1 (a) The 'normal' view of a sine wave. (b) An alternative representation.
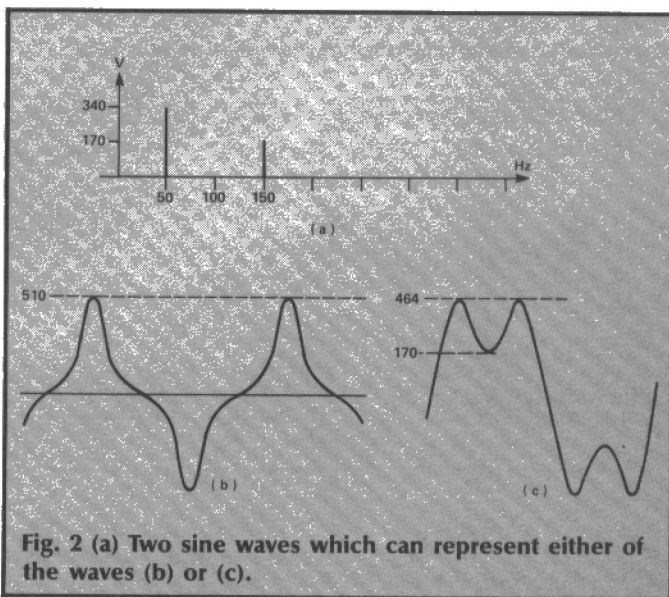
Fig. 2 (a) Two sine waves which can represent either of the waves (b) or (c).

frequencies introduced would be the sub-carrier and its sidebands separated by multiples of the line frequency, which neatly fills the gaps left by the monochrome spectrum (Fig.3b). The half-line offset means that the sub-carrier frequency will cancel out to some extent on successive pictures (not fields) but a sub-carrier of too low a frequency and too high an amplitude would still cause some very unpleasant effects.

The moral is that it is very important to keep an eye on the practical interpretation of abstract information! The offset used in the PAL system, by the way, is ¼ line rather than ½ line — this simple explanation leaves out some other rather significant considerations which mean that ½ line offset is not the best choice but the principle still applies.

Yet another representation of a sine wave is shown in Fig4a, and it's this one I really want to concentrate on.
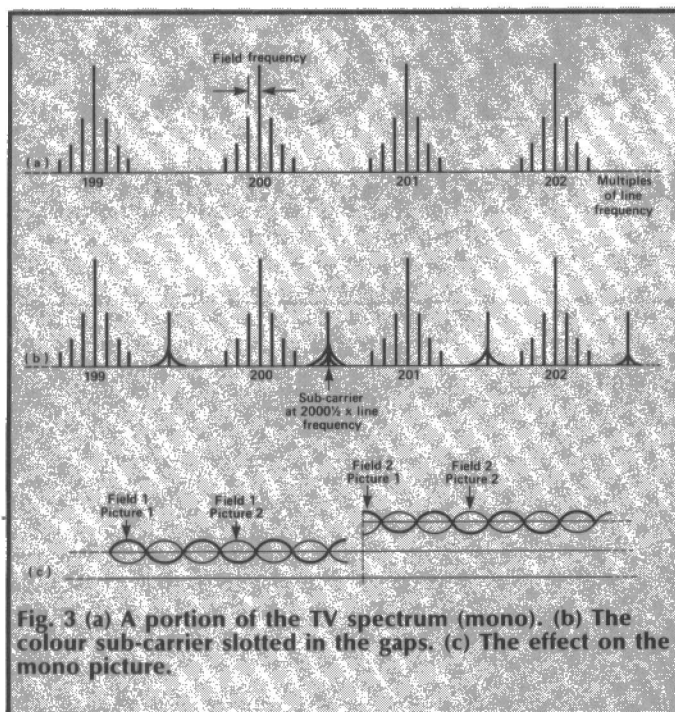
Fig. 3 (a) A portion of the TV spectrum (mono). (b) The colour sub-carrier slotted in the gaps. (c) The effect on the mono picture.
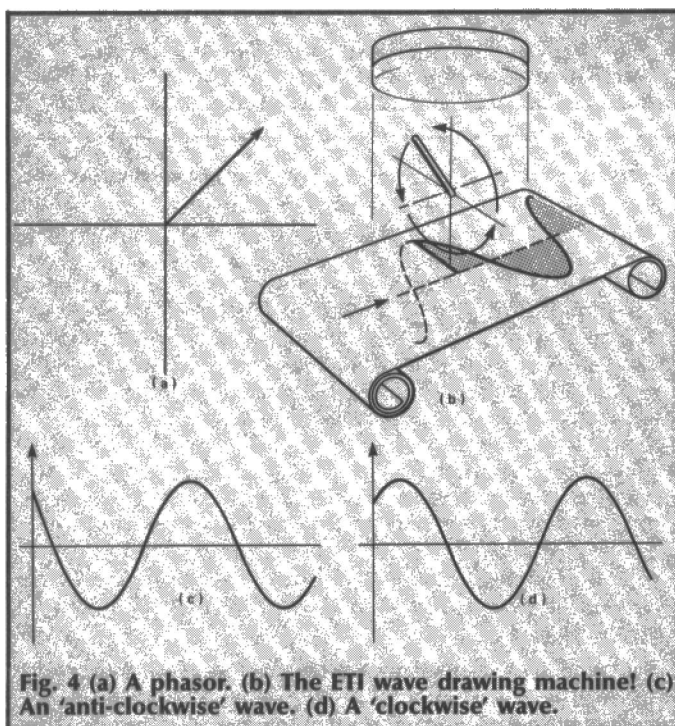

Fig. 4 (a) A phasor. (b) The ETI wave drawing machine! (c) An 'anti-clockwise' wave. (d) A 'clockwise' wave.

A complete cycle of the sine wave corresponds exactly to one rotation of the baton. The amplitude will be equal to the longest shadow cast by the baton which will happen when it is horizontal and so will be equal to its length. The phase relative to a cosine will be equal to the angle the baton makes with the horizontal when the machine is started up. In other words, if I gave you a photograph (or a diagram) of the initial position of the baton and told you the speed of rotation, you could predict exactly what sine wave the machine would draw. That brings us back to Fig.4a.

The direction of rotation of sine-wave drawing machines is important. Figure 4a could draw either Fig.4c or Fig.4d depending on which way it was turned. By convention, sine wave drawing machines always turn anti-clockwise, so Fig.4c is correct.

Diagrams like Fig.4a are called phasors. The most significant loss of information here is frequency — I have to tell you how fast the rod is rotating. You can't tell from the diagram. This may seem like rather an important piece of information to lose but often it can be assumed from the context. If I draw phasors for UK mains powered equipment, for instance, I don't need to keep mentioning that it's at 50Hz. Sometimes circuits run at a certain frequency by design — oscillators, switching regulators, radio transmitters. At other times it can be useful to know how a circuit responds to a certain frequency. In all these cases, frequency is part of the 'background' information and it's the phase and amplitude of the waves that we want to investigate. This is where phasor diagrams come into their own.

Just as several waves of different frequencies can be included in the same frequency spectrum diagram, waves

If you haven't seen this kind of diagram before, it will take a little imagination to see how it works. Just suppose for a moment that the arrow on the diagram is actually a piece of wood baton pivoted at the origin, with its free end moving steadily in an anti-clockwise circle. Now suppose that there's a spotlight above it and a screen below. As the baton moves, the shadow on the screen will shorten until the rod becomes vertical, then lengthen again in the opposite direction, then shorten again until the rod is pointing downwards, and so on.

Now suppose that instead of a screen, the shadow is cast on a strip of photographic material that is exposed by darkness (don't ask me where you can buy it!). The photographic strip is moved along by the same invisible motor which is turning the baton (I said you'd need a good imagination!). When the paper is developed, it will have a trace on it as Fig.4b. A sine wave!

Fig. 5 (a) Adding two waves on the phasor diagram. (b) The resultant wave. (c) Adding out of phase waves. (d) The wrong result. (e) The correct answer. (f) Cancelling waves.

at the same frequency but with different amplitudes and phase can be drawn on the same phasor diagram (Fig.5a). Since both waves are at the same frequency, the two rods are locked together and rotate at the same speed. This gives an easy graphical way to find the sum of the sine waves of the same fequency.

To find the result of adding the two waves of Fig.5a, we want a rod which casts a shadow equal to the sum of the two individual shadows. A crooked rod that will do the trick can be made simply by nailing the two rods together, keeping their angles with the horizontal axis the same. The result is shown in Fig.5b.

The final step is to notice that a straight rod from the origin to the tip of the crooked rod will cast the same shadow, so this is the phasor representing the sum of the two original waves.

If you think about it for a moment, you'll see that it makes no difference which phasor is drawn first when adding. If you try it both ways on the same diagram, you'll end up with a parallelogram with the sum as one of the diagonals.

One thing to remember is that you must draw the phasors in the right direction. Take the extreme case of Fig.5c, for instance. The sum of these phasors is Fig.5d and *not* Fig.5e. If the two phasors had the same length, adding them would bring the end point right back to the origin (Fig.5f). This is equivalent to saying that two sine waves of the same frequency and amplitude but 180° out of phase will cancel each other out when added.

The phasors for a sine, cosine, –sine and –cosine are shown in Fig.6a. A sine wave of any phase you choose can be expressed as the sum of a sine and a cosine. Figure 6b shows a particular example:
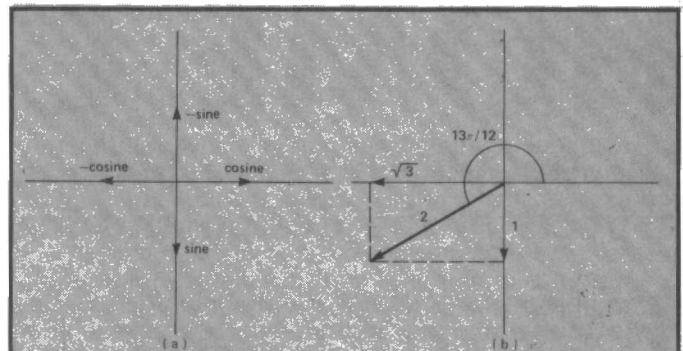
Fig. 6 (a) The phasors for sine, cosine, –sine and –cosine. (b) Expressing a wave as the sum of a sine and a cosine.

$$2 \cos(\omega t + \tfrac{13\pi}{12}) = \sin(\omega t) - \sqrt{3}\cos(\omega_s)$$

The phase angle $13\pi/12$ disappears. In the articles on the Fourier series I mentioned in passing that the series contained both sine and cosine terms to avoid the need for phase angles and this shows how the trick is done. Another piece of the jigsaw falls into place! It's rather like resolving a force into two orthogonal components (which you probably remember from your school days). Just a minute, orthogonality, now that rings a bell too!

So far we've only just scratched the surface of phasors, so I'll continue with the topic next month. In the meantime you may like to look for a way of finding the difference between two sine waves on the phasor diagram. If you really want to show off, see if you can find a way to show the effect of differentiating and integrating a phasor.

ETI

HOME CADMAT

Ian McCulloch gets a helping hand from his computer for all aspects of the design and manufacture of electronic projects.

Equipment for CADMAT (Computer Aided Design, Manufacture and Testing) has been available to industry for a number of years. Over the last two or three years, software packages have become available for a few more domesticated computers (IBM PC, BBC micro, Spectrum, and so on) which perform some of the functions of a CADMAT system (notably circuit and PCB design).

An ideal CADMAT system would allow the user to design the circuit to PCB level, simulate the circuit response, construct the unit on the PCB and test the unit all with one system. It would be rare for a home constructor, who generally builds projects on a one-off basis, to require all of this. It is also generally true to say that those software packages which are available to the home constructer fall into two categories — too expensive or too simple!

The answer is to build up your own system from scratch and this article is intended to give the necessary guidelines and hints to enable the amateur electronics enthusiast to build up a system to suit his own requirements.

The basis for this article is a CADMAT system which I designed using an expanded Microtan 65 system and many of the hints will apply directly to that. Owners of other machines may need to make modifications to suit their own systems but the principles are valid for any computer system.

The design of a unit can generally be subdivided into three stages; System design, Circuit design and PCB design. A possible fourth stage of IC design is way beyond the scope of most home constructors.

System Design

In point of fact, the generic term 'system design' caters for all aspects of design including circuit design and IC design (after all, a circuit, even an integrated-circuit is a system) but for our purposes we will use it to describe the design of what will be the block-diagram of our system. The final product of our work here will be a description of the forms of input and output signals which we will need to produce and the processes that we will need to carry out on them to obtain the next signal. We can, if we wish, also make the computer draw our block-diagrams for us.

It is up to you to produce the basic block diagram. However, when it comes to working out the component values you will require a system simulation. That will mean deriving the transfer function for all or part of the system being designed.

The computer cannot help you here. However, it can lend a hand with the simulation. This will normally require solving differential equations and although these are horrible to deal with 'by hand' the application of the Euler Algorithm can make the process almost pleasurable.

For example, the antenna rotator system of the block diagram in Fig. 1 has the transfer characteristic:

$$H(s) = \frac{C}{R} = \frac{n^2}{S^2 + 2z\omega_n S2\omega n^2}$$
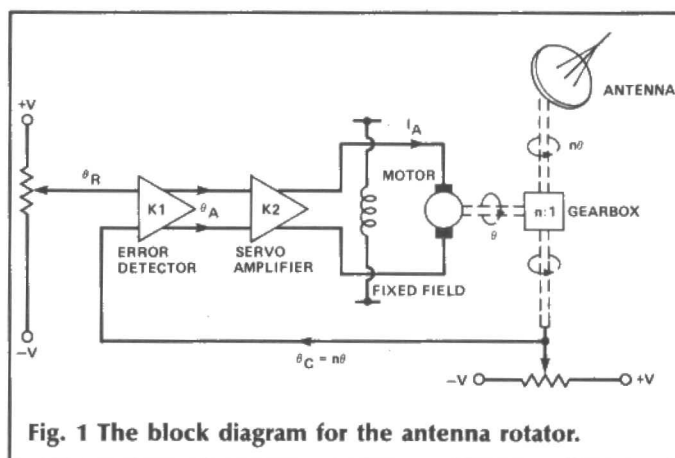
Where C is the output, R the input and

Fig. 1 The block diagram for the antenna rotator.

$\omega_n{}^2 = nK_T K_2 K_1 / R_A J$ (S and S^2 are the first and second derivative of θ). This looks pretty horrific to anyone. However, the Euler Algorithm gives us:

$$C = C + \frac{dC*T}{dt}$$

$$\frac{dC}{dt} = \frac{dC}{dt} + \frac{d^2C*T}{dt}$$

Although that doesn't look too inviting either, the comparatively simple Basic program of Fig.2 is an implementation of the Euler Algorithm for this system and will allow you to evaluate the system response over a selected period of time and alter component characteristics until you are happy with it.

This will form part of the program which performs the analysis. Since this technique requires only input and output routines and basic arithmetic techniques, those of you who are happy programming in machine code will have no problems writing the software in machine code for greater speed.

Circuit Design

Now we have chosen values for our system components which give satisfactory results in the system simulation, we design the circuitry which will make up these components.

Anybody who has used the graphics on their computer will probably realise that to construct a symbol for an individual component is relatively simple. A resistor for instance is simply a rectangle of a size you choose to suit the video resolution of your machine. The video resolution of any given system is in fact the only limiting factor on the size and complexity of your component symbols. It is worth terminating all discrete component symbols in 'nodes' as shown in Fig. 3. This will make your life easier later on when you want to interconnect them. Digital packages can also be simulated in this way and I think it is worth digressing for a moment to explain a slightly different technique you may consider worth using.

Rather than representing standard circuit sections in their usual 'circuit diagram' manner, it is more useful to

```
10 GOTO150
20 REM***SUBROUTINE-IMPULSE***
30 IF X=0 THEN R=1/T
40 IFX>0THENR=0
50 RETURN
60 REM***SUBROUTINE-PAGE***
70 PRINT: USR(62)
80 PRINT"PRESS 'C' TO CONTINUE"
85 PRINT "PRESS 'S' TO STOP"
90 GET C$:IF C$="" THEN90
100 IFC$="C"THEN120
105 IF C$="S"    THEN STOP
110 GOTO80
120 B=0
130 PRINTTAB(5);"TIME";TAB(25);"OUTPUT"
140 RETURN
150 X=0
160 PRINTTAB(B);"SYSTEM IS W†2/(S†2+2ZWS+W†2)"
170 PRINTTAB(6);"-----------------------------"
180 PRINT:PRINT
190 PRINT"Type of input required:-"
200 INPUT "(Enter 'IMPULSE' or 'STEP')   ";R$
210 PRINT
220 INPUT "Value of omega (W)   ";W
230 PRINT
240 INPUT "Value of zeta (Z)    ";Z
250 PRINT
260 INPUT "Steplength required    ";T
270 PRINT
280 INPUT "Integration time required     ";E
290 PRINT
300 INPUT  "Are these values correct (Y-N)?    ";Y$
310 IFY$="N"THEN150
320 B=9
330 PRINT"RESPONSE OF W†2/(S†2=2ZWS+W†2)TO ";R$
340 PRINT
350 PRINTTAB(16);"ZETA= ";Z
360 PRINT
370 PRINTTAB(15);"OMEGA=  ";W
380 PRINT
390 PRINTTAB(10);"STEPLENGTH=  ";T
400 PRINT
410 C2=W†2*R
420 PRINT TAB(4);"TIME";TAB(22);"OUTPUT"
430 PRINTTAB(4);X;TAB(23);C
440 B=B+1
450 IFB=20THENGOSUB60
460 IFR$="STEP"THENR=1
470 IFR$="IMPULSE"THENGOSUB20
480 C=C+C1*T
490 C1=C1+C2*T
500 C2=W†2*R-2*Z*W*C1-W†2*C
510 X=X+T
520 IFX<ETHEN430
530 IFZ>=1THEN610
540 PRINT
550 PRINT"CALCULATED DAMPED OMEGA IS:-"
560 PRINTTAB(6);W*SQR(1-Z†2);"RAD/SEC"
570 PRINT
580 IF R$="IMPULSE" THEN600
590 PRINT"CALCULATED OVERSHOOT IS ";EXP(-Z*π/(SQR(1-Z†2)))*100;"%"
600 PRINT
610 PRINT: INPUT"CHANGE ALL DATA (Y-N)"I$
620 IFI$="Y"THENGOTO150
630 END
```

Fig. 2 A simple Basic implementation of the Euler algorithm.

lines of course), otherwise, a much simpler approach may be to move the curzor under manual control and draw in the line as the cursor moves. The choice is yours.

Most circuits are made up from combinations of several simple circuits whose transfer response is generally known (it is often just a matter of looking it up). So far, we have used the computer as a sort of graphics tablet to produce the picture of the circuit. We can now use it to obtain the component values.

It is necessary to give the computer a list of preferred component values. An array is the simplest approach, although this is a little tedious. The technique I have used is to build up a library of transfer characteristics, including each new circuit as I need it. Once again, the simulation techniques using the Euler Algorithm are used. You may choose to build up the library in this way, gradually, or you can go for broke and build up a comprehensive library in advance. The choice depends on personal preference (and patience).

On my system, once the circuit is drawn on the screen, the user is prompted to the analysis. For simplicity, the analysis takes the form of typing in the name given to the circuit at the front-end and the input signal. Subsequent circuits are selected from a menu displayed on the screen and the input assumed to be the output of the previous circuit. Circuit branches (where two or more circuits are driven from one output) are chosen at the menu and the system returns to this point when an end (or a mixer stage) is indicated. Branching should be minimised at the system design stage. Components (labelled when the circuit is drawn) are evaluated by the computer and a list is output at the end of the program.

This analysis can be simplified if the system is reduced during the system design stages until each system component contains only a serial set of 'standard' circuits with external branches.

The techniques I have just described hold true for both analogue and digital simulation but in the case of digital simulation, the 'standard' circuits are the logic gates and devices used. Here, the computer simulation is even easier since most micro-processors contain as standard the Boolean operators needed to simulate more complex devices — even up to a microprocessor if you have the patience to evaluate it (I'm told it can be done). For microprocessor circuits, I generally stop at the picture stage and only use the analysis for peripheral circuits, but again this is up to you.

PCB Design

Actually producing the artwork for a printed circuit board from a well produced circuit diagram is usually a straightforward process. Simple PCB design packages have a selection of pad configurations (8-pin DIL, 14-pin DIL) and a variety of track widths. The software finds the shortest route between two chosen pads and draws the track between them.

If you use the design method suggested earlier and you're careful how you design your circuit it may be possible to transfer your design directly to PCB artwork (the 'nodes' are now the pads). This is usually relatively easy for fairly simple circuits designed on a single sided PCB.

Double sided PCBs are easier if you have colour available on your machine. The component side will be drawn in one colour, the solder side in another (red and green are easy to distinguish from each other). This can be incorporated at the circuit design stage although you may need to take care in choosing which links occur on each side of the PCB.

The screen resolution of your computer will limit the size of PCB you can display. If you need to display a larger

consider them as ICs. So a J-K flip-flop, rather than being drawn as four NAND gates, would be represented by a 14 pin chip labelled 7400 (or whatever). A further benefit of this method becomes apparent when you transfer your circuit to a PCB design.

Most micros can produce programmable characters on screen which can be used to make up DIL packages for this purpose.

In order to link the terminals of two or more devices a line must be produced from one node to the next. If your programming is good, you may elect to write routines to find the shortest route (without crossing any

Fig. 3 Discrete circuit symbols with nodes.

PCB, careful memory usage will allow you to display sections of the PCB at one time and so you can design boards of almost any size you choose. However, don't forget that a screen with four colours and a resolution of 256 by 256 requires 16K of memory. That means you would require 64K of storage for a PCB of four 'views' so don't get carried away!

The output can be to either a printer or plotter. I find a plotter works better than a printer and some fairly cheap models are now available. You will find that if you store the symbols you use in your designs as part of your plotter character set, the circuits and PCB designs can be drawn much faster. Double sided PCBs done in two different colours take a little care. Remember that each colour must be printed separately. Pads and so on which occur on both sides of the PCB can be done in a third colour (which can conveniently be a mixture of the other two).

One last point about your printer/plotter. You will need to dedicate the required number of serial or parallel I/O ports to your output device. Remember those used for this will not be available for other devices (unless you feel like changing the devices connected to the ports for each stage of the analysis and design).

Computer Aided Manufacture

It is unlikely most amateur constructors will use automation to build their projects. However, anybody who enjoys experimenting with robots may well enjoy attempting the design of a unit to assemble components onto a PCB and for those people I will list some of the considerations and techniques they may wish to use.

Before starting work on the unit, you must first decide what exactly you require of it. Do not be too ambitious. Even a simple unit is likely to be a difficult enough prospect for most people.

The construction process is best considered in stages. The software which drives the unit must determine what component is required in each position on the PCB. For simplicity, since it is unlikely that any of you will possess anything more complex than a relatively simple robot arm, I would suggest that you pre-form the components and store them separately according to type and value. This will reduce your problems but it still doesn't make it easy.

The next stage will be to control the robot arm via the computer and make the gripper pick up a single component from the correct tray. Finally, you will need to orientate the component correctly and insert it in the correct position on the PCB.

Obviously, some form of vision system will be req-

uired to ensure the correct orientation of the component. This can be achieved with little difficulty if you can get your hands on a large capacity RAM chip with a 'lid' — the square metal plate on top. If the lid is heated with a soldering iron it comes off fairly easily. This is then replaced with a small piece of clear plastic glued into place. When the power supply rails are connected to the supply, you will find that you have a perfectly serviceable CCD camera.

With the appropriate software in your computer the image can be compared with that of a similar component correctly orientated. By moving the component until the images match, the correct orientation of the component can be ensured.

One aspect of computer aided manufacture which will probably be of far more interest to most home constructors is that of PCB drilling. The device I use, and which is probably by far the simplest, is an independent programmable unit. The locations of the holes are stored in memory as each hole on the first PCB is drilled. Future
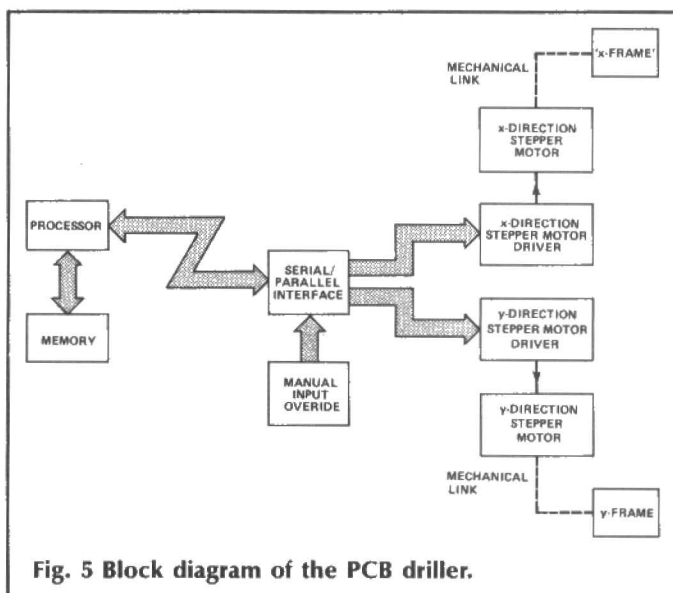

Fig. 5 Block diagram of the PCB driller.

PCBs can then be drilled with ease. The first stage is to construct a sturdy frame along the lines of those used on X-Y plotters (Fig. 4). The drill will be rigidly mounted and the PCB moves in a frame using two stepper motors. The control unit (either a joystick or a keypad) moves the frame and when the pad to be drilled is underneath the drill bit, the position of the pad (X-Y cartesian co-ordinates) is stored in memory. Once all the pads are stored, the computer will move to each pad in turn and drill the required hole. The only limitation on the number of holes is the amount of memory you provide.

The block diagram of such a system is shown in Fig. 5. The flow-chart for the software required is shown in Fig. 6. This software is best written in machine code but if you elect to control the drill from your computer, there is no reason why the software should not be written in any high-level language which you have available.

Computer Aided Testing

In industry, there are essentially four phases of testing. These are device testing, board testing (in-circuit testing), system testing, and field testing. In practice the cost of each of these stages is about ten times the previous stage.

For the home constructor, field testing is unlikely to apply but the other three stages will be relevant. Device testing is mainly a matter of common sense. Routines for individual devices (AND, OR, NOT, etc) are needed plus a ZIF-socket connected to one of the ports on your computer. By generating the required inputs to the device
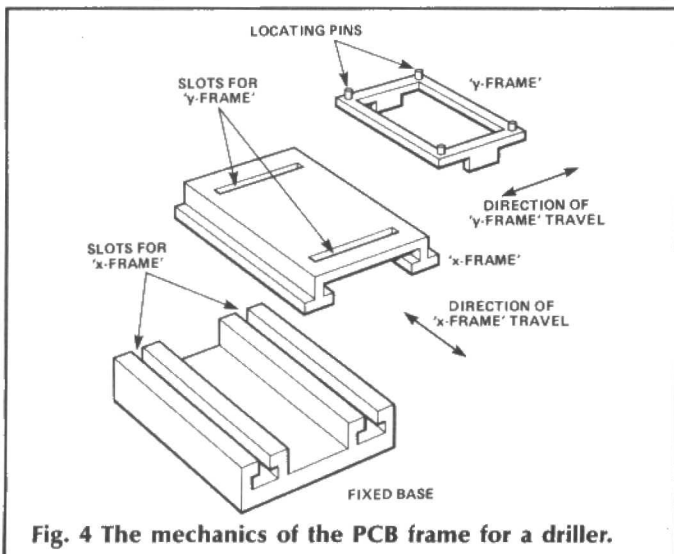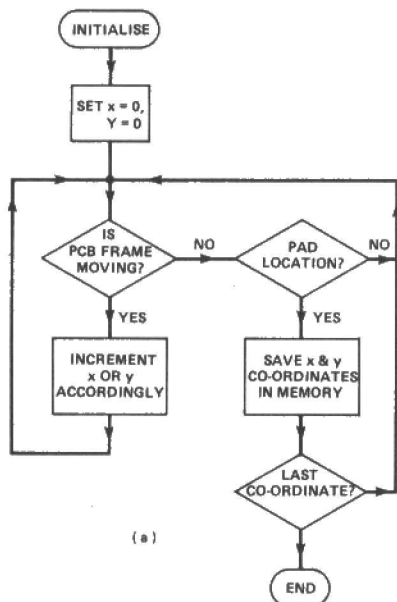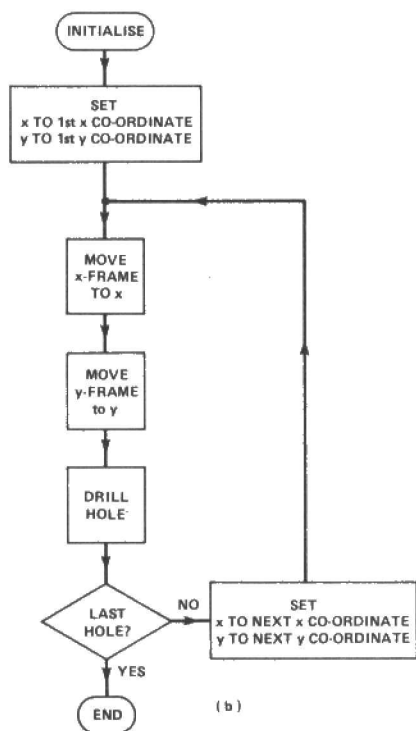

Fig. 4 The mechanics of the PCB frame for a driller.

Fig. 6 Flowcharts for the PCB driller software.
(a) Setting up the coordinates. (b) Drilling.

and monitoring the outputs, the operation of a device can be easily checked.

I shall deal mainly with the testing of digital circuits although I will include a few tips for those wishing to write and implement routines for analogue circuits. For board testing or system testing there are two main testing techniques (apart from random testing which is so inefficient we can ignore it). These are 'centre-split testing' and 'end-to-end testing'. Both of these techniques can apply to either digital or analogue circuits.

Centre-split testing is the technique in which the unit under test (UUT) is divided into two parts and tested at its mid point. If the signal measured at the test-point is correct, the fault lies after the test point. If it is not then the fault lies before the test point. The suspect circuit section is then similarly sub-divided until the fault is isolated. This technique works well for single faults but can be extremely time consuming if multiple faults are present.

End-to-end testing is self-explanatory. A known signal is applied to the input and the test-path follows the signal flow through the unit.
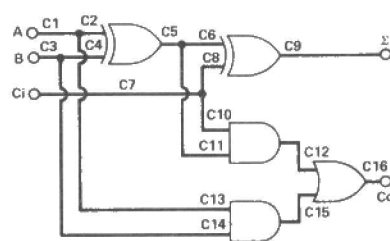
Digital systems present several unique problems to the test engineer. In analogue systems, the signal follows a simple path from input to output. Digital Systems are frequently processed in parallel and it is necessary to monitor a large number of signal paths simultaneously. In a system with a high clock rate we will require a large data buffer, since we are not able to monitor the sequence of digital words. The signals stored in the data buffer can later be observed and the fault (hopefully) diagnosed.

In a bus-constructed system where several devices have access to the bus, it is possible for a fault in device B to corrupt data being passed from device A to device C. A fault on one bus line can corrupt all data passing through the system.

When feedback occurs in a digital circuit, any fault in the feedback loop will corrupt all data in the loop and at all nodes subsequent to it.

It is by no means simple to determine whether a fault in a digital system lies in hardware or software. Hardware faults may cause corruption of software whereas a software fault may lead the engineer to suspect the hardware.

LSI devices can cause problems due to the limited pin-outs. Pins are often used for both input and output or for both data and address. For data obtained in tests to be meaningful, quite sophisticated control of the UUT

Fig. 7 The circuit diagram and fault cover for a full adder.

INPUTS			O/P		1/0	1/1	2/0	2/1	3/0	3/1	4/0	4/1	5/0	5/1	6/0	6/1	7/0	7/1	8/0	8/1	9/0	9/1	10/0	10/1	11/0	11/1	12/0	12/1	13/0	13/1	14/0	14/1	15/0	15/1	16/0	16/1
A	B	Ci	Σ	Co																																
0	0	0	0	0		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓
1	1	1	1	1	✓		✓		✓		✓		✓	✓	✓		✓		✓		✓		✓		✓		✓		✓		✓		✓		✓	
0	1	0	1	0		✓		✓	✓		✓		✓		✓			✓	✓		✓	✓			✓		✓	✓			✓					✓
0	1	1	0	1		✓	✓		✓		✓		✓		✓		✓		✓		✓		✓	✓			✓	✓			✓				

2/0 REPRESENTS NODE C2 s-a-0   2/1 REPRESENTS NODE C2 s-a-1

is required by the test equipment.

Timing errors may only become apparent at specific clock frequencies and intermittent faults require monitoring of the UUT for long periods with sophisticated data storage and triggering to capture the fault effect together with the data sequence which preceded it.

A fault (although permanent in nature) may occur only under specific (perhaps even rare) input conditions. Tests of I/O devices and lines must be extensive and careful.

These are just some of the problems specific to digital systems. The development of a comprehensive test system is beyond the average home constructor. However, we can consider the likely requirements of such a system.

If we are testing a system which we have designed ourselves, we will know (or at least should know) all the possible signal combinations for given input signals at all points through the circuit. In order to determine whether or not a unit is fault-free, it is usually only necessary to monitor the output while all possible input signals are applied to the input.

If a fault occurs in a digital circuit, it is likely to fall into one of two categories; a connection stuck at one (s-a-1) or a connection stuck at zero (s-a-0).

Consider the circuit of a full adder shown in Fig. 8. Each of the connections is labelled Cn. For a three input system as shown, it is obviously possible to have eight input words. Test minimisation is required in industry where time is often at a premium but for the home-constructor (who can usually afford to be more leisurely) it is often easier to use all inputs than to determine which are necessary for full fault cover.

Analogue systems may be similarly tested. When the signal at a particular test point in the circuit is known, a sample and hold circuit and Analogue to Digital con-

vertor can be used to obtain a digital signal corresponding to the analogue voltage. This is compared with a digital version of the expected signal. Do not forget to make allowance for tolerances when you test. If the measured signal is within 10% (for some circuits the error due to circuit tolerances can be up to 50%) of that expected then the signal is probably correct. You are likely to find limitations here from the conversion rate of your ADC, system-clock rate and your programming ability.

This article is intended to give an introduction to the problems and techniques involved in the design of simple CADMAT systems for home use. Undoubtedly, different micros will present advantages and problems for anybody wishing to construct such a unit and a good knowledge of you specific system is going to be vital.

I have provided some basic guidelines only and not a detailed guide to constructing a system. Further help can be obtained from reference books. Four which I have found useful are:

Engineering Mathematics (2nd edition) by K A Stroud (MacMillan).

Appllied Circuit Theory Matrix and Computer Methods by P R Adby (Ellis and Horwood).

Network Analysis and Synthesis by F Kud (Wiley).

Introduction to Control Systems (2nd edition) by D K Anand (Pergammon Press).

In addition, anybody having problems is welcome to contact me at the address below and I will attempt to sort them (the problems that is) out.

Ian McCulloch
5 Knighthead Point
Westferry Road
Isle of Dogs
E14 8SR.

ETI

INSIDE HYBRID'S MUSIC 5000

Chris Jordan, creator of the Music 5000 synthesiser for the BBC micro, explains the hardware behind the sounds.

Hybrid Technology's Music 5000 synthesiser for the BBC micro is an amazingly powerful music peripheral for a relatively low cost (see last month's review). It uses exclusively low cost off-the-shelf components as an alternative to the semi-custom and custom devices used in many other modern digital instruments.

To obtain this combination of power and cost-effectiveness, an ingenious and well thought-out design was required.

One of the most important features is the independent control of each channel and voice (collection of channels). In particular, this means that every voice can use a different 'instrument' (overall sound and character). This is essential in a computer music peripheral, in contrast to a keyboard synthesiser where typically only one instrument sound is needed at a time.

Each voice also has separate volume and pan controls so basic mixing desk functions are provided without need for a separate unit, and with full computer control.

Table 1 summarises the hardware elements of each channel and Fig. 1 shows how they are arranged. All the other voice and channel functions, including pitch conversion, envelopes and modulation are implemented in software on the host computer. We will look at each hardware element in turn.

Oscillator

The oscillator (see Fig. 2) is a 'phase-accumulator' type of digital oscillator. This is analogous to an analogue rampwave oscillator.

Where an analogue oscillator uses a capacitor to determine the phase and a charging current for the frequency, the phase accumulator digital oscillator uses an accumulator and an incrementing value, respectively. The cycle length of the analogue oscillator is determined by a level detect and discharge path. In the digital oscillator this is achieved by the accumulator overflowing.

The accumulator consists of an adder and a register, whose value at any moment is the current phase (the position in the cycle). The increment value is drawn from the frequency register. On each update ('sample') of the oscillator, the frequency is added to the phase, possibly causing the phase to overflow and return to the start of the cycle.

The Music 5000 uses 24-bit frequency and phase words giving very high resolution. Just the top byte of the phase is used as the output so you can think of the complete oscillator a a 16-bit oscillator feeding an 8-bit up-counter, which outputs a ramp wave.

The output frequency is:

$$\text{update rate} \times \frac{\text{frequency}}{\text{maximum frequency}}$$

$$\text{maximum frequency} = 2^{\text{(number of bits)}} = 2^{24}$$

One point to note is that a constant frequency resolution is available over the full range — particularly

Fig. 1 The functional block diagram of the Music 5000 synthesiser.
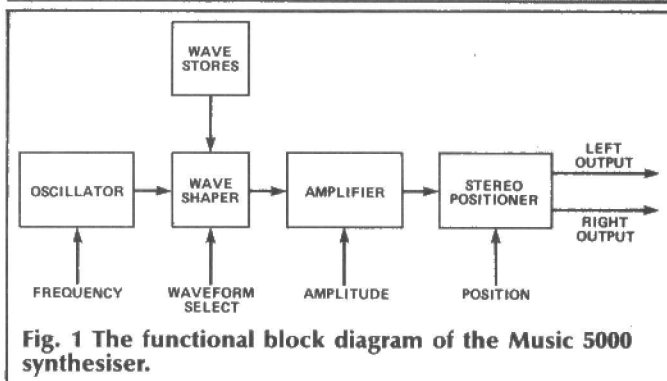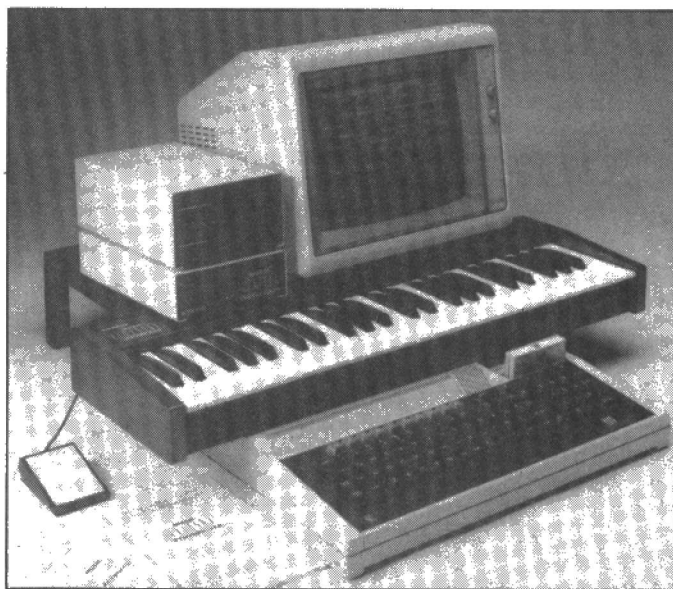
Oscillator with frequency control to 0.0056Hz resolution
Wave shaper with 14 128-byte waveform stores
Attenuator with 7-bit logarithmic control
Stereo positioner with seven output positions
Outputs with 47kHz sampling rate and 8-bit exponential resolution

Table 1 Hardware functions of each of the 16 channels

important for fine detuning effects. Cheap computer sound generator ICs use the alternative 'divider' method which gives a frequency resolution that decreases with increasing frequency.

Wave Shaper

The oscillator produces a ramp wave. This is easily converted into any other shape by addressing a waveform table. Fourteen 128-byte tables in RAM are available, so a 4-bit waveform select and 7-bit oscillator output are combined to address the waveform RAM.

Amplifier

This is the block whose operation is least obvious although its job is quite simple — to allow control over the wave-shaped signal's amplitude by multiplying by a variable value. The direct approach is not on because a digital multiplier IC would be far too costly and so would a DAC with sufficient resolution to handle its output (12 bits minimum).

Our answer is to perform the multiply by the addition of logarithms. In fact, we work in terms of division by an attenuation factor with a minimum of one so the amplitude is always reduced.

$$\log (\text{output}) = \log (\text{input}) - \log (\text{attenuation})$$

$$\text{output} = \exp (\log (\text{input}) - \log (\text{attenuation}))$$

We are left with four operations to carry out: add, logarithm (twice) and exponent (anti-log). The add is quite straightforward. The log of the attenuation never needs to be worked out, since the whole system works in logarithmic amplitude control anyway. For example, an envelope decay calculated as a straight line takes a logarithmic shape when played. The log of the input value is calculated by the software, the waveform values being converted to log form on sending to the wave stores.

The final exponentiation is carried out by an exponential DAC, also called an anti-log or 'companding' DAC. This simply produces an analogue output which is the exponent of the digital input.

Stereo Positioner

The final block takes a single signal and divides it between the left and right output channels to determine its stereo position. This extra stage of amplitude control is achieved by very high speed 'chopping' of the analogue signal. In each of six successive timing slots, each channel is fed either the true signal value or zero, according to a three-bit stereo position control. When both channels receive the signal for three slots, the position is central. When one side gets it for all six slots, the signal is entirely on that side. Six slots give a convenient total of seven positions.

Outputs

The left and right outputs each have a four-pole low-pass filter which reconstruct the signals from their sampled and chopped form. Buffer amplifiers present the signal to the connector at the rear of the case. The output level appears to be quite low in normal use. This is because, being a computer-controlled synthesiser, a wide range of level is possible and the gain has been set to make sure the maximum level does not overload the typical hi-fi amplifier DIN input.

Sound Quality

There are three aspects to the sound quality of an all-digital synthesiser:

- output resolution
- dynamic range
- sampling rate

In most cases, the output resolution is simply that of the DAC, typically 8 or 12 bits. In a true synthesiser (not a 'sampler') the full-signal output resolution alone is much less important to overall sound quality than is often believed.

Far more important is the dynamic range or, more precisely, how quiet a signal can become before distortion is unacceptable. The problem is that although a resolution of, say, eight bits, can reproduce a full-amplitude signal acceptably, a signal of 1/256th of this amplitude (−48dB) will be converted with 1-bit precision.
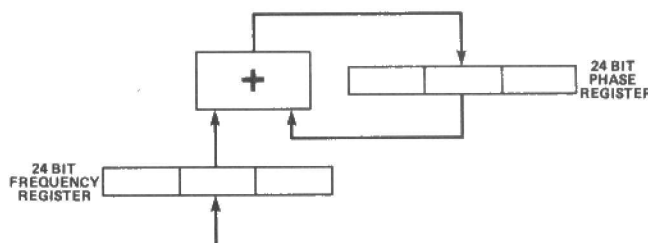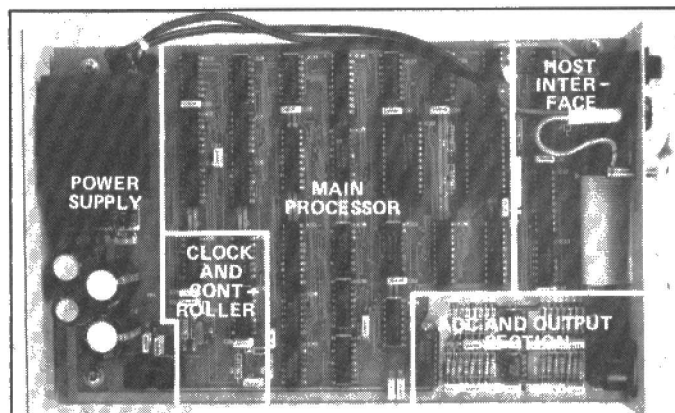

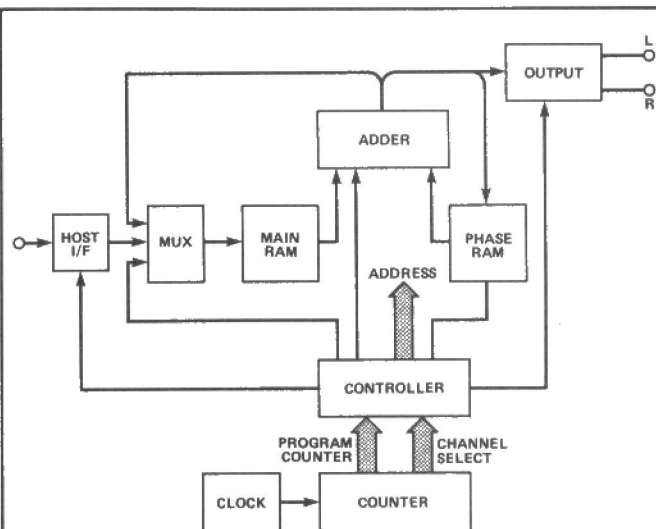**Fig. 2 The 'phase accumulator' digital oscillator.**

Fig. 3 Implementation block diagram of the whole synthesiser.

The resultant distortion of quiet sounds is unacceptable in a high quality system.

The 'companding' characteristic of the DAC used in the Music 5000 gives the small-signal precision (and therefore a dynamic range) of a 12-bit linear DAC — quite adequate for high-quality synthesis, where no reproduction of recorded sound is necessary.

Since the digital input is still only eight bits, there must be a trade-off at the top of the output range. In fact the precision at the limits is about three percent, roughly equivalent to a 6-bit linear DAC. On a single *recorded* signal this would give unacceptable distortion ('quantisation noise') but in the Music 5000 each of the 16 channels is converted separately and the effect is merely that you don't get *exactly* the waveform you ask for.

The last consideration is sampling rate. Again, the effect of this in a synthesiser design is often misunderstood. It has nothing to do with 'sampling' natural sounds but describes the fixed rate at which the synthesiser computes and converts the output signal and hence the

fastest changes in the signal that can be reproduced accurately.

The sampling rate sets a limit on the maximum frequency that can be faithfully reproduced. The distortion effect known as 'aliasing' occurs when the frequency exceeds this. With a synthesiser, you expect to be able to play the same sound over a wide pitch range so the design needs a margin of safety on top of the acceptable rate for 'sampling' or recording at comparable quality.

Sampling rate also influences the sound quality through interaction with limited output resolution since 'a finite sampling rate will cause each step in the waveform to 'jitter' back and forth in the final signal.

You can alternatively think of this as the aliasing of the high frequencies in the steps of the waveform. Either way, the result is noise which may be heard as a 'graininess' in the sound. The Music 5000's high sampling rate of 47kHz minimises noise. Since such noise only occurs along with a sound and not continuously, and it is independent for all channels, its audibility is reduced further by masking.

Implementation

The synthesiser uses a pipelined, fixed-program digital signal processor constructed largely from LS TTL devices. It runs at six million instruction cycles per second (requiring 120ns RAM access time) and uses 8-bit data words. The program computes and outputs each channel sample in eight instruction cycles (1.2µs), and since there are 16 channels, this gives a total program loop time of 19.2µs.

The 12MHz crystal-controlled clock and 8-bit counter generate the 3-bit 'program counter' (instruction number) and the 4-bit channel select. The controller is the site of the 'program' and generates control signals and addresses for all other blocks.

The interface from the host computer (the Beeb) is via a simple bus and is write-only (on the BBC Micro, the synthesiser appears as eight 256 byte pages in the 1MHz bus extended address space). On a write operation, the value is buffered and the DSP transfers it to the internal registers on the first instruction of the next channel loop, that is, within 1.2µs.
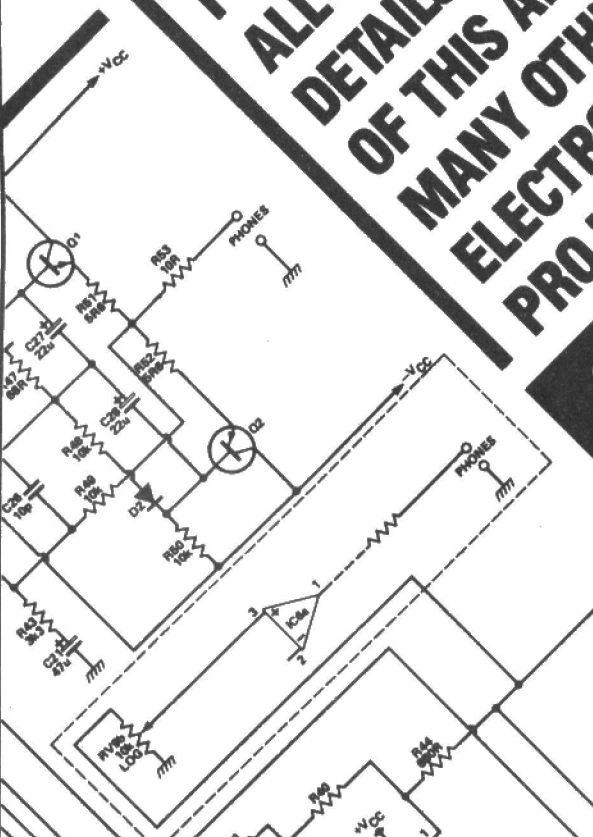
The 2Kx8 RAM provides the wave stores and those registers to which the host computer has access. A multiplexer supplies its address — from the controller on register instructions, from the buffered register address on the host transfer instruction and from the waveform number and phase (at the ALU output) on the wave-shaping instruction. The frequency is held in three bytes.

The phase RAM holds the phases for all channels (each in three bytes). The frequencies and phases are stored in separate RAMs, each at an input to the adder so that the time-consuming 24-bit oscillator add can be carried out efficiently. The phase RAM is also a 2Kx8 device, so only a small part of it is actually used.

The adder is eight bits wide. It is used by every second instruction in the eight instruction loop, once on the amplifier instruction and once on each of the three oscillator instructions so the 24-bit phase is added in three bytes. A 1-bit register takes the carry from the output to the input and is cleared at the start of each multi-byte add by the controller.

The output block includes the DAC, stereo position chopper and low-pass filters for left and right outputs. It receives the output of the ALU on the amplifier (log add) instruction and the stereo position value. **ETI**

HARDWARE DESIGN CONCEPTS

Mike Barwise attempts to convert us all to proper ADC and DAC design techniques.

Since the microcomputer revolution, analogue-to-digital and digital-to-analogue converter devices have become quite familiar and the various mechanisms and types have been widely publicised.

However, there is seldom any great emphasis placed on performance or precision in projects handbooks. So, it is my intention to describe the design, layout and adjustment procedures required to attain maximal performance out of any data conversion chip.

I have chosen one ADC product and one DAC product for this discussion. The part numbers are HI-574 ADC and HI-DAC16 DAC. These have been picked for a good reason. The ADC is a de facto 12-bit industry standard and requires no complex external logic allowing us to concentrate on design and adjustment for performance. The DAC is a state-of-the-art fast 16-bit DAC which will, incidentally, be of interest to the digital audio enthusiast. Both parts are from Harris Semiconductor.

Design Criteria

First we must consider what we mean by performance. The two most important adjustable characteristics of any data conversion device are *zero setting error* and *full scale calibration error*. So what do they mean?

Zero setting error (also known as offset error) is a user adjustable characteristic and describes the correlation between a digital word 00 and 0V at the analogue end.

Full scale calibration error similarly describes the deviation from the ideal of maximum analogue voltage corresponding to maximum digital word. This error is also adjustable. There are several other important parameters including *Linearity* and *noise performance* which influence device selection but cannot be directly user adjusted.

Noise performance can be adversely affected by user implementation. The published figures (generally very low these days) assume optimised test conditions and more or less describe the interaction across the silicon chip itself.

Linearity is the only characteristic over which the user can have *absolutely* no influence. The linearity of any given device depends on the precision with which the internal resistor chain (in the case of DAC and successive approximation ADC devices) or other comparison system is manufactured. Any ideal data conversion device has a specified analogue voltage span (frequently 0-10V) and a range of digital input or output words representing equal sub-divisions of that voltage span.

There are two categories of linearity error — overall and differential. Overall linearity describes the accuracy of approximation to this ideal. That is, how closely each analogue step corresponds to its theoretical value. Overall linearity is usually well specified in device data and is seldom worse than one bit less than the nominal resolution. So, for a 12-bit converter (HI-574) the cheapest
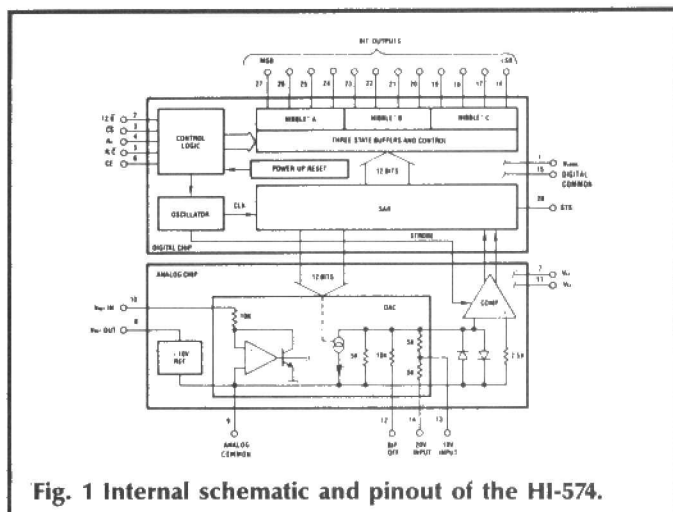

Fig. 1 Internal schematic and pinout of the HI-574.

device in the series is specified at 11-bit linearity. This means there can be two adjacent steps somewhere among the potential 4096, which are too close together or too far apart. However, there will be some transition in the correct *direction* of digital output ADC or some change in the correct *direction* of analogue output DAC for every minimum resolvable change in input.

Differential linearity error, on the other hand, manifests itself as either no change or a change in the *wrong direction* for a given minimum resolvable input change. This is a far more damaging error to performance than overall linearity error and you minimise it by spending a bit more on your chips, to get a better selection grade.

The Problems

The first stage in good data conversion design is layout. In all but the crudest of systems, and anywhere more than 7-bit (one part in 128) resolution is required, it is crucial to design and lay out the circuit so that:

● digital and analogue signals cannot mix.

● analogue signal lines are as far as possible immune to external pickup.

● reference voltage sources are stable and do not drift. The first two factors affect system noise which will manifest itself in the ADC as random variations in digital data for a nominally stable input voltage. This will effectively limit ADC resolution as an uncertainty is introduced into the low order digital bits. In the DAC noise pickup will show as bad glitches (spikes) during transitions between input values (digital system noise pickup) or as a superimposed random analogue signal component (and/or hum) on the analogue output whether the digital input is changing or not.

Where an external voltage reference is used (many

modern devices include their own internal reference) instability (wobble) or drift (gradual change) will shift all the step transition thresholds up or down causing, in gross cases, the wrong digital word to be associated with a given analogue voltage.

Another factor which will affect noise is *throughput.* Throughput is the real system conversion rate which includes conversion time, digital data handling time and conversion triggering overheads. At best it is a little less than the reciprocal of the conversion time shown in the device data. You can, of course, adversely affect throughput (by software control using Basic, for example) but you can never improve on it beyond the published limits for a given device.

These days most data converters are so fast that the maximum throughput will normally exceed your requirements except in the most strenuous of situations. However, you *must* prove this by calculation before building expensive circuits!

You should also take throughput into account from the noise generation standpoint anywhere you are working near the throughput limit of a data conversion component. Really top grade components are usually accompanied by graphs of throughput versus noise (or in other terms, bandwidth versus effective resolution). You can generally assume that as the throughput approaches design maximum, effective resolution and throughput become inversely proportional.

Design Rules OK!

The first rule is: *always use a ground plane for data conversion circuit boards.* A ground plane is a continuous area of copper on the component side of the board connected to ground.

A ground plane encompassing the whole data conversion chip should normally be considered as analogue ground and this should be separated from a ground plane under the digital support circuitry by a gap at least 1mm wide. Each of these ground planes should be connected by a separate wide track to a common grounding point (star grounding). This ensures that any digital noise introduced into the data conversion will for practical purposes be the noise of the converter digital half only. Within the analogue ground plane the manufacturer's recommendation for grounding should be *strictly* adhered to, as requirements vary depending on the internal layout of the chip.

This fiddling around with fancy ground tracks *is* necessary. Considerable currents flow in the analogue and digital grounds of data conversion chips and of course we already know about the noise spikes in logic ground tracks. Our aim is to stop these currents interacting while avoiding the creation of any appreciable voltage drop between the nominal ground at the ground plane and actual ground. A star earth configuration fulfils this requirement by providing a short path from each device ground to the common point but a long path (two short paths in series) between any two ground pins.

If current is flowing out of the ground pins of two devices on a star ground they cannot mix, as they both flow independently into a common current sink. Any fluctuations or spikes at one ground pin will similarly disappear into the sink. If we simply wired all our grounds in sequence to a common bus, current spikes in the ground of the device furthest from the real ground current sink can disturb the next device via its ground pin.

This bus grounding technique is acceptable in audio work, where you have more control over the ground currents of your devices. In that case, devices are connected to the ground bus in ascending order of power/ground current towards the real ground sink. In
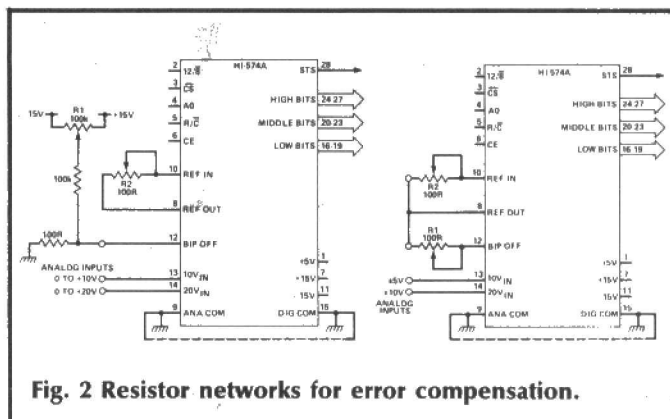

Fig. 2 Resistor networks for error compensation.
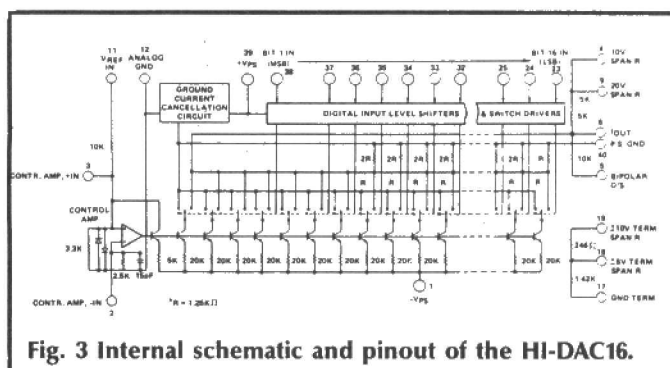

Fig. 3 Internal schematic and pinout of the HI-DAC16.

this way there is a current gradient in the ground bus, which is, as a result 'quieter' at the small signal end of the system.

Unfortunately, this option is not open to us in data conversion, as the ground current characteristics are less consistent in the time domain (they are spikey and device-state dependent).

Making Tracks

Rule two: *keep analogue and digital signals separated.* Examination of both the ADC and the DAC shows that the manufacturer has carefully allotted one side of the device to analogue signals and the other to digital signals. This is one of the ways the low specified noise figure is achieved but we can screw it up by bad circuit board layout! Ideally there should be a physical separation and some grounded tracking at the boundary between the analogue and digital signals. The two should not run in adjacent or in crossed tracks.

In practice this can be relaxed somewhat to make layout easier. For practical purposes, tracks which cross at right angles (on opposite sides of the board!) will not cause appreciable interaction even if one is carrying digital and the other analogue signals, unless you are going for resolution in excess of 12-bit. Adjacent *parallel* tracks carrying digital and analogue signals are not a good idea (particularly on the same side of the board) but if you interpose a grounded track of at least the same width so that the signal tracks are some twice their own width apart and keep the parallel portion short, you can also get away with it for resolutions to 12-bit.

A good technique for longish analogue signal lines (more than 3in) is to use a screened cable strapped or glued to the ground plane side of the board with its screen grounded *at one end only* and preferably near the centre of the star ground.

Rule three (the last basic rule): *whenever possible transfer digital data in or out via fast parallel registers.* The use of registers such as 74LS (or S)175 or 374 on the digital interface will for ADC chips clean up and speed up the output at the expense of a one conversion delay

in data availability and also to some extent isolate digital bus noise from the ADC.

For DAC devices, it substantially reduces digital bus noise, reduces glitch noise and cleans up transitions where the DAC bus width is wider than the driver bus width. I have now established that the 'flow through' pinout parts (such as 74F574) are a lot better as noise barriers than the 374. This is possibly due to the increased physical separation between input and output pins (input on left, output on right) because as far as I know, the silicon layout is much the same.

More Info On Examples

Now we have some basic guidelines for laying out data conversion chips, let us have a quick look at our example devices. First, ADC. The part number is HI-574A, and it is a 12-bit (1 in 4096) converter with various modes of operation determined by hard wiring of programming pins. Its simplest implementation is as a 12-bit parallel output converter triggered by a STROBE. The chip generates a STATUS signal which can be used to clock the parallel data into a set of registers (or a FIFO of the sort I described last month!). This is a 'successive approximation' ADC and its internal diagram is shown in Fig. 1.

It is apparent that much of the low noise characteristic is due to the device being a hybrid of two separate chips (one digital and one analogue). For information on mode programming I recommend the Harris analogue product data. Fig. 2 shows the resistor networks required for adjustable error compensation.

The DAC (also by Harris) is shown in schematic form in Fig. 3. This consists of a precision reference, a resistor ladder network and a set of switching transistors. The resultant device is a *current* output DAC with a resolution of 16-bits (1 in 64K). To generate an output *voltage* an op-amp follower is needed, as shown in Fig. 4. This also indicates grounding requirements and the resistor networks needed for adjustable error compensation.

Nulling Errors

Theoretically it should be possible to apply a 0V signal and adjust the offset error of an ADC to zero by checking for a digital word of zero. Similarly for the DAC, apply a zero digital word and adjust the offset for a 0V output. In the same way the maximum voltage could in theory be set up for both components.

However, there is a problem, particularly in the case of the ADC. The specified voltage corresponding to a given digital word is in fact the centre point of a finite step. This means that at that point *nothing will happen.* What we have to do is calculate the *transition point between two adjacent steps and compare that with the indecision* between two adjacent codes.

Taking our 574 as the example, we have 12-bit resolution. This yields 10V/4096 or 2.44mV per step. As 0V will give output zero and 2.44mV will give output one, the transition can be expected half way between these values — at 1.22mV. So, zero setting is performed by applying 1.22mV and adjusting the offset pot until the output code flickers evenly betwen 0 and 1. Similarly the last transition occurs 1½ bits or 3.66mV below 10V, or at 9.9963V.

In the case of the DAC (when used in voltage mode) analogue zero is adjusted for a zero digital word, and maximum output is set at 9 bits below 10V for a maximal digital word. Note that this is a compromise due to the difficulty of driving the DAC with a pair of alternating words and the even greater difficulty of reading the resultant fluctuating analogue voltage. The resultant calibration will never be quite as good as that of the ADC.

To really achieve maximal calibration accuracy, the DAC should be driven with evenly alternating 0 and 1
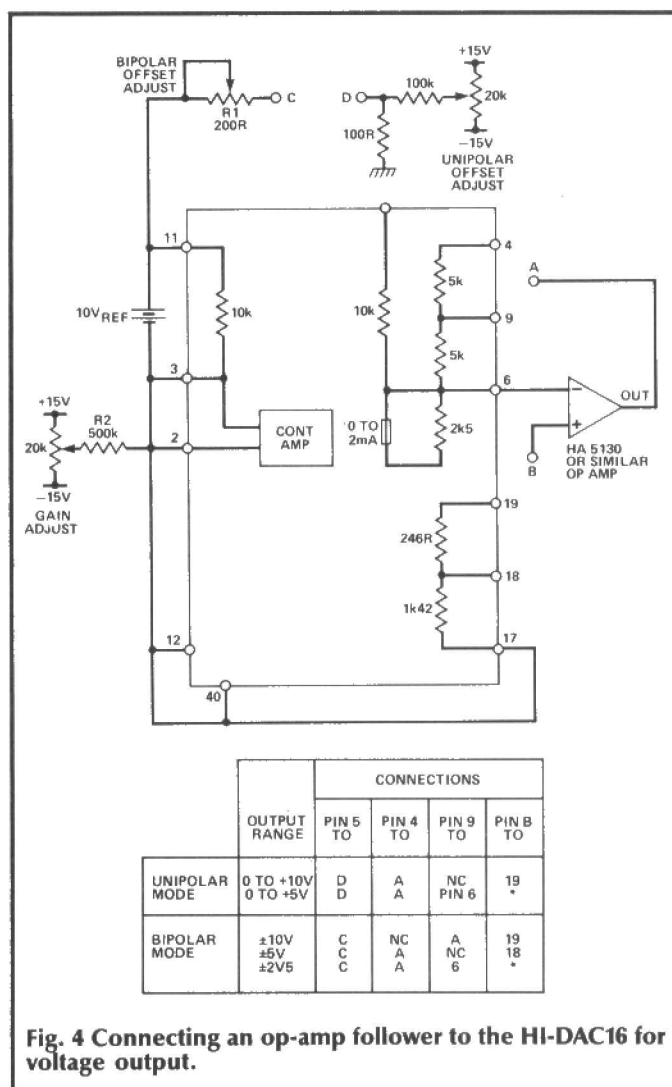

Fig. 4 Connecting an op-amp follower to the HI-DAC16 for voltage output.

		CONNECTIONS			
	OUTPUT RANGE	PIN 5 TO	PIN 4 TO	PIN 9 TO	PIN B TO
UNIPOLAR MODE	0 TO +10V	D	A	NC	19
	0 TO +5V	D	A	PIN 6	*
BIPOLAR MODE	±10V	C	NC	A	19
	±5V	C	A	NC	18
	±2V5	C	A	6	*

(offset adjust) or max/max-1 (full scale adjust) at a high frequency (about half the maximum conversion rate). The DAC output should be integrated using a series R, parallel C network and the resulting output examined. Provided the timing of the two words is even, you should be able to set up the transition voltage as for the ADC. As this device has 16-bit resolution, the maximum voltage is specified much more precisely, at 9.999847V.

These are the only two adjustments required for simple implementations. Note that if you use a sample and hold with an ADC, this will need offset nulling as well, *independently.*

That about wraps up the background to data conversion, except a few parting truisms. Get and *read* the chip manufacturer's data sheet. If you have difficulty calibrating your system (using reliable test gear) suspect noise and if there is noise, suspect your layout before anything else (particularly grounding).

Finally, unless you have a precision voltage source available which is accurate to at least ten times the resolution required, forget it! It is pointless to try calibrating something using an unreliable reference. It is better in such circumstances to use devices of less than 12-bit resolution *uncalibrated* (yielding about 10-bit at best) than to attempt the impossible.

Components are advancing all the time and I hope to introduce new devices from time to time. I am currently looking at some 8-bit ADC devices capable of up to 35MHz conversion rates. Together with our FIFOs these will make excellent digitisers. However, these chips have ECL interfaces so next month I will take a look at elementary ECL. Watch this space!

ETI

BIG DIGITS

Don Scarrott is visible from yards away with this large numerical display. The number and size of the digits is limited only by your imagination.

Many clubs would like to have a large digital display for scores or timing but the cost of electronic displays rises rapidly as the size increases. In any case such displays don't usually exceed three or four inches and this is not big enough for a large crowd.

This mechanical 7-segment display costs about £20 for the components per digit, *irrespective of their size* (although this does not include the time spent in design and construction). Size of the digits is fixed more by where you are going to put the display or considerations of portability but it can range from eight inches as a reasonable minimum, to eight feet or more!

The design is mechanical in that each segment is driven by a small electric motor, although CMOS chips are used to look after the counting, selecting and sequencing. So, instead of a LED or LCD, we have decided to call it a MED, for Mechanical/Electronic Display.

Mechanical Details

Detailed dimensions will not be given as these will depend on what the constructor has available but we will describe the main design points for an eight inch high, three-digit MED. This was designed to display minutes after zero hour for an orienteering club. It had to be weatherproof and portable, so it runs off two 6V lantern batteries and is mounted inside a waterproof cover, as shown in Fig. 1. The cover was made from plywood and hardboard, with a perspex panel on the front and it was waterproofed by covering it with self-adhesive plastic. The ON/OFF and other switches are mounted underneath, where they won't get wet. The display is mounted on a vertical main panel with the battery box built onto the back as a buttress to give rigidity. Obviously, this design can be easily altered to suit your own requirements.

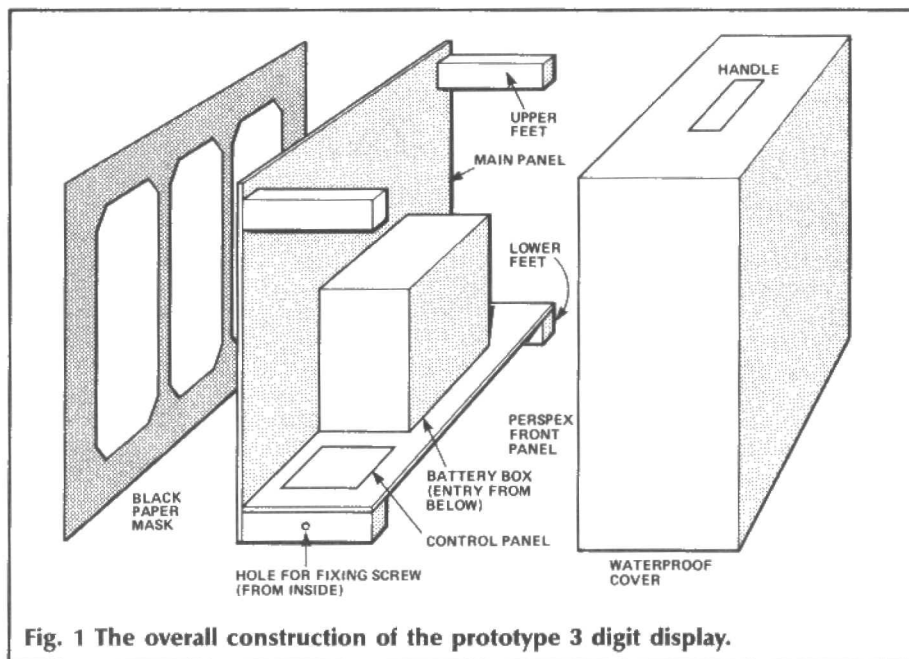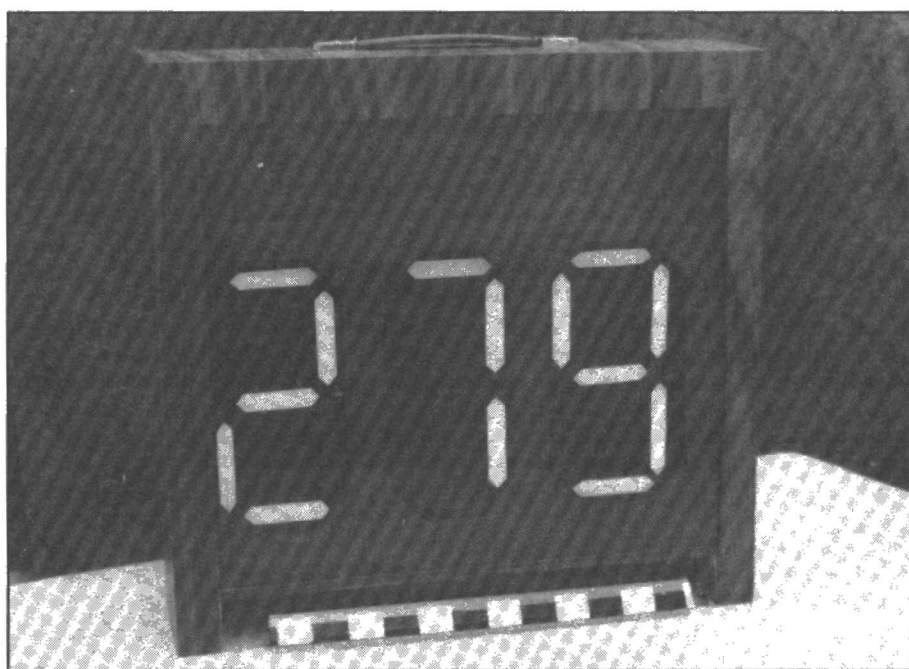Figure 2 shows the lower case letters used to identify the seven

Fig. 1 The overall construction of the prototype 3 digit display.

segments used for each digit. Each segment is driven by a cheap, permanent-magnet motor of the type used to drive toy cars. A piece of thin galvanised wire is stuck onto the end of the motor shaft using an epoxy resin and a short metal sleeve. The end of the wire is bent at right angles and is located in a bracket as shown in Fig. 3. The bend or the bar on the bracket allows the shaft to rotate only through half a revolution. Stuck to the wire is a cardboard vane, white on one side (typing correction fluid) and black on the other (blackboard paint).

When the motor is driven one way it shows the white side and when driven the other way it flips

to the black side. There is no need to drive it except when changing and so it is economical in power. Dry batteries are suitable so long as no more than one motor is driven at once and so they are driven in sequence over a period of about two seconds.

Figure 4 shows how the segments are fitted together. One set has to be slightly lower than the other to allow the shafts to cross. The background is also painted matt black, and a black paper mask is fitted over the front to conceal the motors and wiring.

Electronics

Two boards have been developed to make it easy to assemble the components. The Digit board (Fig. 5.) contains components for just one digit, so several of them should be built, as needed. The first board also holds any components not required on the remaining boards. There is also a divide-by-six option for applications requiring clock-type displays which is obtained by fitting two extra chips and changing a link.

So, although the PCB is the same for each digit, its contents can be quite different. The between-board wiring diagram shows how to connect them together to form a multi-digit counter.

The smaller Minute board (Fig. 6) provides a negative-going, one second pulse each minute to drive the counter if required. To synchronise this with another clock, press the SYNC button in the 59th second and release it at zero. Check the synchronisation over several hours. If the Minute board is running slow, reduce the value of C3. If fast, increase C3. The range of control is normally limited to a few seconds per day but it can be increased a little by removing C1 and/or C2.
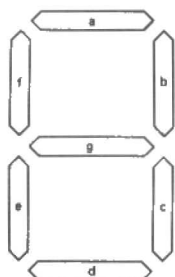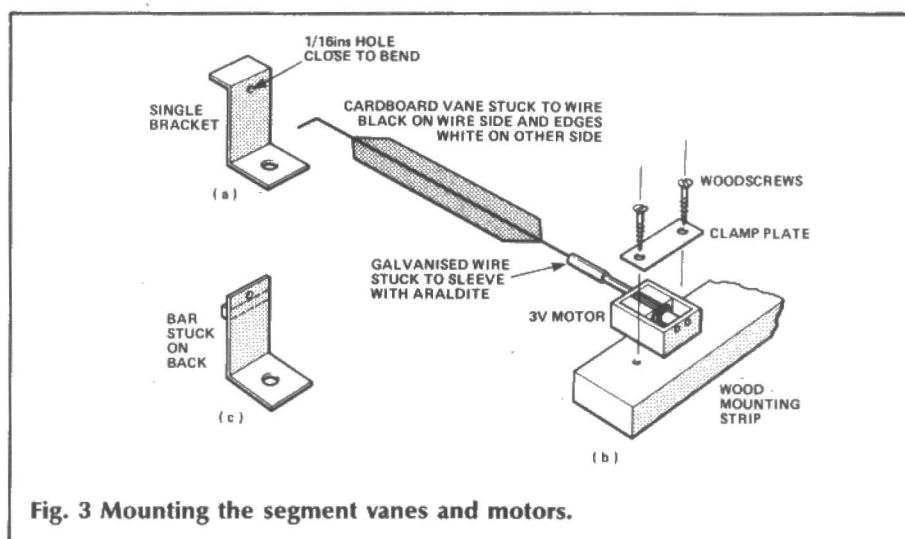

Fig. 2 The seven segments' indentification.

Fig. 3 Mounting the segment vanes and motors.

Using the controls

Each digit has a push ADD button and a SET/RUN switch. If the switch is in the SET position, pressing the ADD button will add one to the corresponding digit. This can be used to set that digit to any desired value. When in the RUN position the add is disabled to prevent the count from being altered by accident but pressing the button still initiates a drive cycle and this can be useful for testing.

Operation

It is best to set all switches to RUN before switching because the display will then be driven to show zero automatically. If the ripple blanking option has been used the digits will show blank rather than zero.

Each digit in turn should then be switched to SET and the desired starting number entered by pressing the ADD button repeatedly. Once the digit is displaying the correct starting point, the switch is thrown to RUN. This is repeated for the other digits.

Negative going pulses from the K input of the first digit will then increment that digit until the upper limit (usually ten but alternatively six if the ÷6 option is installed) is reached. The next digit will then increment and the first digit reset to zero. This chain continues along the digits in the normal way with a ÷10 or ÷6 action at each digit as appropriate.

The negative pulses can come either from the Minute board (for displaying time elapsed) or from the switch input (for recording scores and the like). The switch should be connected between the K input and the negative rail with a pull up resistor to the positive rail.
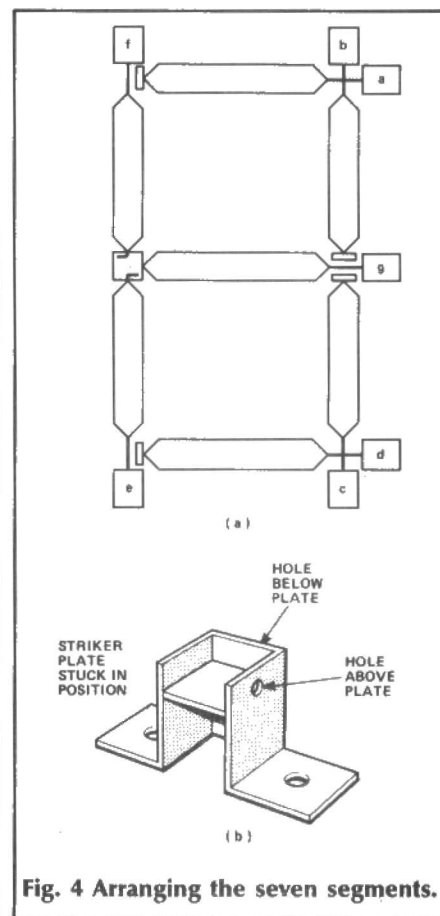

Fig. 4 Arranging the seven segments.

Construction

The small motors used often have a three-segment armature. If they come to rest with one of the brushes across a joint, the starting current flows more or less equally round each side and the motor has trouble starting. When bending the wire to form the stop, choose an angle which avoids this condition.

The mounting described is simple and it does work but it requires the two bearings in the motor to be aligned with the bearing at the other end of the vane. The wire should be flexible
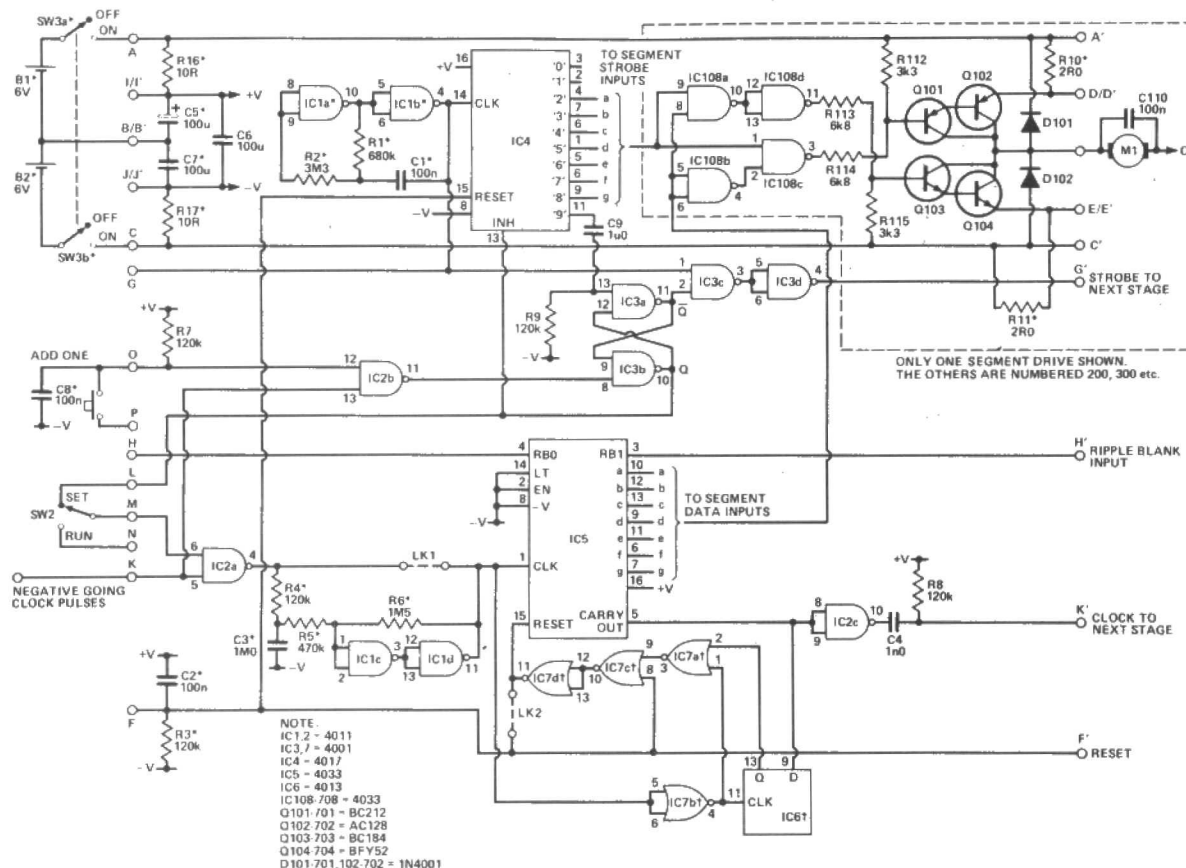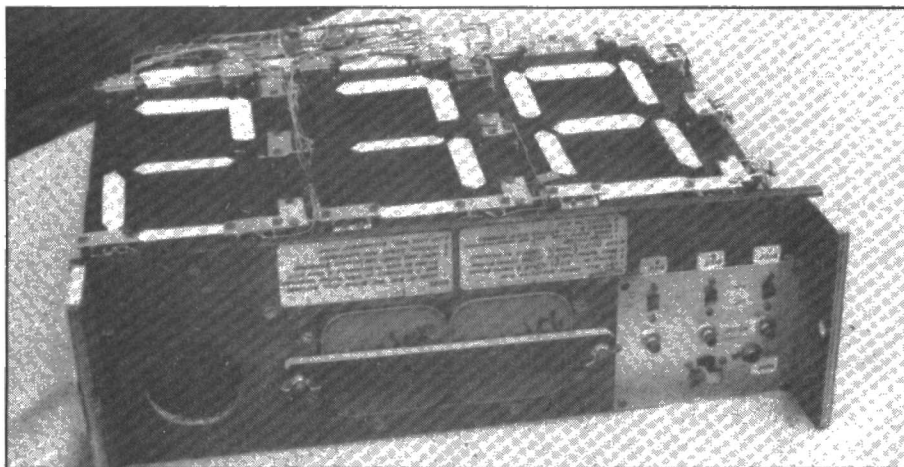
Fig. 5 The circuit diagram of the digit board. LK1 and components marked * for first digit only. LK2 and components marked † for ÷10 only.

enough to give some tolerance but vibration in the back of a Land Rover was found to upset the alignment and cause a jam. To avoid this you could consider alternatives:

● Fix the stop at the motor end of the vane and dispense with the far bearing. This might do for three to four inch vanes but larger sizes may need support.

● Provide the vane with its own two bearings and connect it to the motor by a universal joint. This need be little more than a crank on the motor shaft hitting a bend in the end of the vane spindle.

When glueing the wire to the end of the motor shaft, make sure that the surfaces are clean. Since the diameter of the wire is less than that of the shaft, give the wire more length within the sleeve to make the surface areas similar. The wire acts like a spring to reduce the impulse at the end of the travel so the thinner it is the better.

The two batteries can be mounted side by side in one box.

Its internal dimentions should be 2 11/16 by 5 1/4 by 4 1/16 inches, plus or minus 1/16. Although you can improvise with pieces of tin plate for contacts, a proper battery contact plate PCB will be much easier to install. A suitable foil is shown on the foil pages.

The component overlays for the two PCBs are given in Fig. 7 and Fig. 8. Note the link under IC4 on the Minute board. This should be fitted before the socket for IC4 or on the solder side of the board.

On the Digit board there is nothing critical about the transistors and you may use other types provided they are PNP for Q101, 102 and NPN for Q103, 104. Any small silicon transistor will do for the drivers but the output transistors should be able to supply up to 1A. Note that the BC212 has different pin connections depending on the type suffix.

The common emitter resistors are difficult to obtain in high wattage, and are easier to make from five 10R 0.6W resistors in parallel. Holes are provided for two of them on each board with the intention of spreading them

HOW IT WORKS — DIGIT BOARD

Negative-going clock pulses are connected to the K input. They are inverted by IC2a to clock IC5 which is a decade counter with 7-segment decoded outputs. These go high when the segment should be white. The carry out is inverted by IC2a and differentiated by C4,R8 before being connected to the next stage at K.

The initial reset line at F is normally negative but when first switched on it is pulled up by C2 long enough to reset the counters. The time constant of C2,R2 must be greater than the supply decoupling time constant (R16,C5 or R17,C7) if it is to be effective, whereas C4,R8 and C9,R9 must be less.

For a divide-by-10 stage, link LK2 is fitted and the reset pulse is applied directly to IC5. For a divide-by-6 stage, an extra reset pulse is provided by fitting IC6 and IC7 instead of LK2. IC7c is a NOR gate. By inverting its output with IC13d, the pair become an OR gate applying either of the positive going reset pulses to IC5. IC6 is a D-type flip-flop which makes Q=D when its CLK input goes positive and otherwise ignores D. The carry out from IC5 is applied to D, and it goes negative at the count of five. Because the clock pulse is inverted in IC7b, IC5 triggers on the leading edge, but IC6 waits until the trailing edge before taking Q negative. Q is one input to IC7a. When the IC5 clock pulse again goes positive, the other input to IC7a also goes negative. The output of IC7a therefore goes positive and resets IC5 to zero.

The clock pulse at K is also used to reset the SR flip-flop formed by IC3a and

b. This removes the inhibit on IC4, which is a decimal decoded decade counter. the strobe clock pulses at C now cause its outputs to go high one at a time from zero to nine. The output sets the SR flip-flop once again, which inhibits this counter via NAND gate IC3c and allows the strobe clock through to the next stage. We only have seven segments to drive, so the zero and one outputs of IC4 are not used.

Each segment requires its own driver stage. Only one is drawn in full. Normally the strobe line is negative, so IC108 pins 3 and 10 will be positive, and pin 11 will be negative. The transistors are cut off and there is no motor drive. The segment data line is taken to IC108, direct to pin 8 and inverted to pin 2. When the strobe line goes positive, the output of one or the other of these gates will go negative and drive the motor in one direction.

The motor should be connected so that a positive input drives the segment to black, and negative to white. Even small motors can generate spikes of over 60 volts and diodes D101 and D102 limit these to protect the transistors. C110 should be mounted directly across the motor terminals to reduce RF radiation.

The motor DC resistance is very low. In normal applications the motor runs fast and the back EMF reduces the current drawn from the battery. In this case it no sooner starts than it stalls against the stop so emitter resistors R10 or R11 limit the current to a safe value. Since only one is on at a time, they can be common to all motors on all boards. While they don't normally even get

warm, under fault conditions a motor may stay on and the resistors will burn out unless rated at 3 watts. Even so, there will be a step of about one volt in the battery voltage when a motor comes on. At these low freqencies we cannot stop this from reaching the CMOS circuits but enough supply decoupling is provided to blunt the edges and stop spikes from triggering the counters.

On the first digit LK1 is open circuit and IC1 and its associated components (marked with a *) are included. On the remaining digits, LK1 is made and IC1 and the * components omitted.

IC1a and b form an oscillator running continuously at about 10Hz to sequence the motors. The frequency is determined mainly by R1 and C1. R3 prevents the junction of R1,C1 from being clipped by the protection diodes on the input to IC1a.

R4 and C3 filter out any interference present on the clock input to the first digit. IC1c and d square the clock up again to give a sharp edge for triggering IC5.

For setting up the display each digit has two switches. When SW1 is pressed, it resets the SR flip-flop thus initiating a drive cycle. If SW2 is at SET, it also supplies a clock pulse to increment the digit by one. Once set up, SW2 can be set to RUN and this prevents altering the count inadvertently. The cycle is still initiated and this can be useful when testing. When first switched on, C8 ensures the first digit goes through its drive cycle, otherwise the motors would just stay where they happened to be. C8 is only required on the first digit.

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over all the boards but for testing mount them all on the first board.

Start by mounting the IC sockets, capacitors and resistors, except for R16 and R17. Then fit the transistors for the first segment and connect up one motor which can be allowed to free-run for now. C8 and C110, 210, 310, etc are mounted off the PCB. Connect up the ±6V supply and check the quiescent current is less than 5mA. This really needs two meters, one for the positive and one for the negative rail. However, a switch can be fitted to use one meter in each rail and directly connect the other.

Temporarily connect R113 to +6V, and check that the motor runs smartly in one direction. Temporarily connect R114 to −6V, and check the motor runs in the other direction. If all is well, fit the remaining transistors and check the quiescent current is still less than 5mA.

Next insert the IC's, taking the usual anti-static precautions. Fit a 10k to 500k resistor from K to +6V

to stop the clock input from floating. Temporarily connect the ±6V to I and J, and check the current to all the chips does not exceed 2mA. If it does, switch off and check the chips are the right way round. In this case the supply is not split, so it does not matter whether you measure the current in the positive or negative rail.

These checks over, fit R16 and R17, and connect the boards together, as shown in Fig. 9. Connect the motors to the boards, taking care each motor is the right way round. If you have not got a source of pulses, again fit a suitable resistor from the first board K input to +6V, and a push button from K to −6V. Then pressing the button will provide a pulse to increment the counter.

If a fault results in an output stage sticking on, the motor can get hot and the plastic commutator supports may even melt so you cannot afford to leave it on for long. The meter is useful at all stages of constructions for checking whether excessive

current is being drawn, so you can switch off in time. Feel the output transistors to see which one is getting hot, but watch you don't burn your fingers! A 100R resistor could be inserted in the common motor lead to reduce the current to a safe value while investigating the fault, but the motors will not then run.
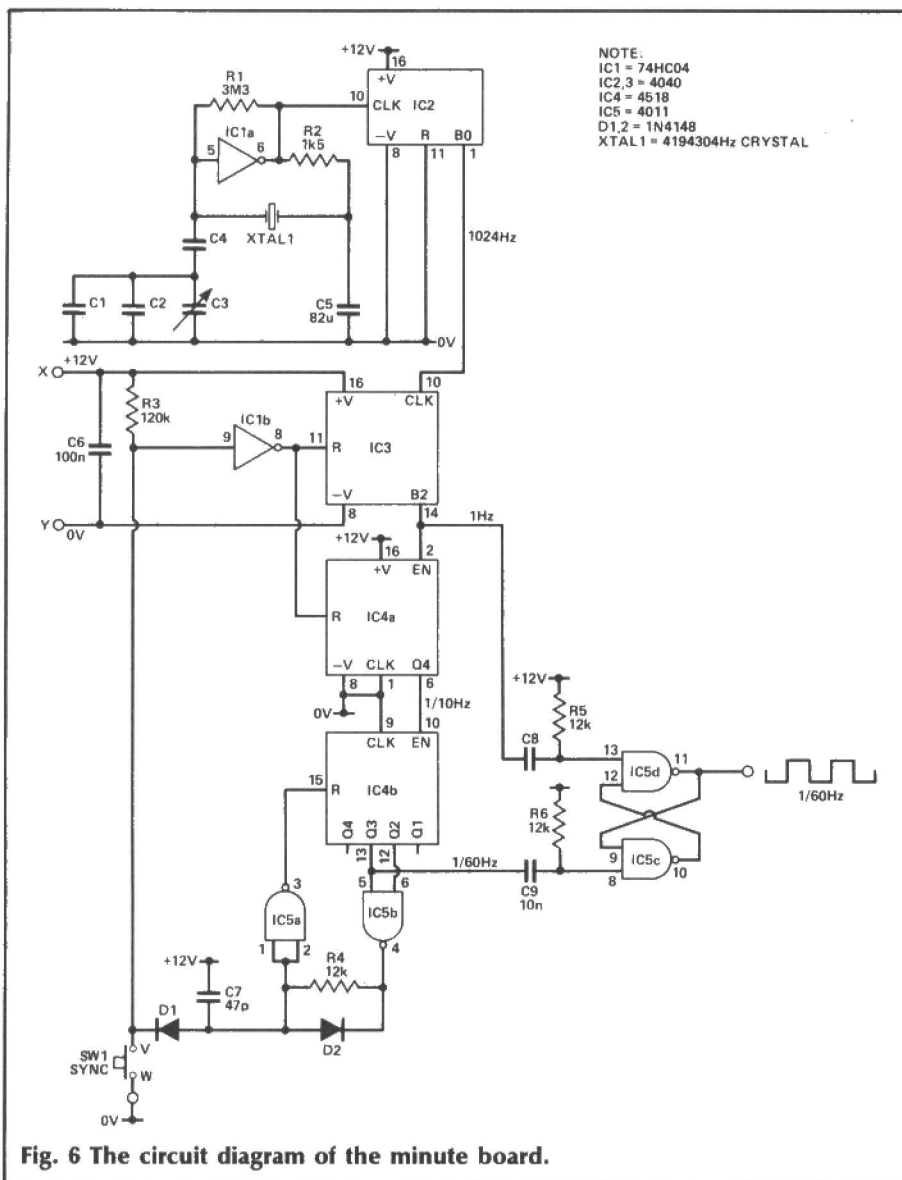
Fig. 6 The circuit diagram of the minute board.

PARTS LIST DIGIT BOARD

RESISTORS all ¼W 5% unless specified	
R1	680k
R2	3M3
R3,4,7,8,9	120k
R5	470k
R6	1M5
R10,11	2R0 3W (see text)
R112-712,115-715	3k3
R113-713,114-714	6k8
R16,17	10R

CAPACITORS	
C1,2,6,8,110-710	100n ceramic
C3,4,9	1n0 ceramic
C5,7	100μ electrolytic

SEMICONDUCTORS	
IC1,2,108-708	4011
IC3,7	4001
IC4	4017
IC5	4033
IC6	4013
Q101-701	BC212
Q102-702	AC128
Q103-703	BC184
Q104-704	BFY52
D101-701,102-702	1N4001

MISCELLANEOUS	
B1,2	6V 'lantern' battery
M100-700	3V DC motor
SW1	SPST push-button
SW2	SPDT switch
SW3	DPDT switch

PCB; case materials; galvanised wire; metal sleeving; steel plate (for motor brackets); segment vanes; nuts and bolts.

PARTS LIST MINUTE BOARD

RESISTORS all ¼W 5%	
R1	3M3
R2	1k5
R3	120k
R4-6	12k

CAPACITORS	
C1,2	10p ceramic
C3	5-65p trimmer
C4	47p ceramic
C5	82p ceramic
C6	100n ceramic
C7	1n0 ceramic
C8	10n ceramic

SEMICONDUCTORS	
IC1	74HC004
IC2,3	4040
IC4	4518
IC5	4011
D1,2	1N4148

MISCELLANEOUS	
SW1	SPST push-button
X1	4194304Hz crystal

PCB; wire; nuts and bolts.

HOW IT WORKS — MINUTE BOARD

X1 and IC1a form a crystal oscillator running at 4194304Hz. The output is fed into IC2 which is a 4040 12 stage binary counter. This divides by 4096 to give 1024Hz at pin 1.

IC3 is also a 4040, but only the first 10 stages are used, to give 1Hz at pin 14.

IC4 contains two similar four stage counters, normally forced to divide by 10. If the Enable pin is held high and the input applied to the CLK, we get a positive edge trigger. If the CLK is held low and the input is applied to the enable pin, we get a negative edge trigger. Normally either would do, but to reset properly we use the negative edge trigger.

The first half of IC4 divides by 10. The second half has Q2 and Q3 taken to a two-input NAND gate, IC5b. Its output goes low when the count reaches six. This pulls C7 down rapidly via D2 and, through IC5a, resets the count to zero. IC5b output goes smartly back up again but C7 takes a little time to discharge via R4 and so the reset pulse does have a finite length.

IC5d and IC5c are connected as a Set-Reset flip-flop. The inputs are normally held positive by R5 and R6. The minute pulses are differentiated into short spikes by C9, and the negative going spikes set the flip-flop, causing the clock board output to go negative. The 1Hz pulses are differentiated into even shorter spikes by C8, and these negative going spikes try to reset the flip-flop. One of them will occur at the same time as the minute pulse but the 1Hz pulse will be overridden because it is much shorter. However, the next 1Hz pulse will succeed and the output is a negative going pulse lasting for exactly one second each minute.

When SW1 is pressed, both counters are reset via D1 or IC1b, allowing them to be synchronised with another clock. To be absolutely precise, the count begins when SW1 is released, rather than when it is pressed.

Fig. 7 The component overlay for the digit board. LK1 and components marked * for first digit only. LK2 and components marked † for +10 only.
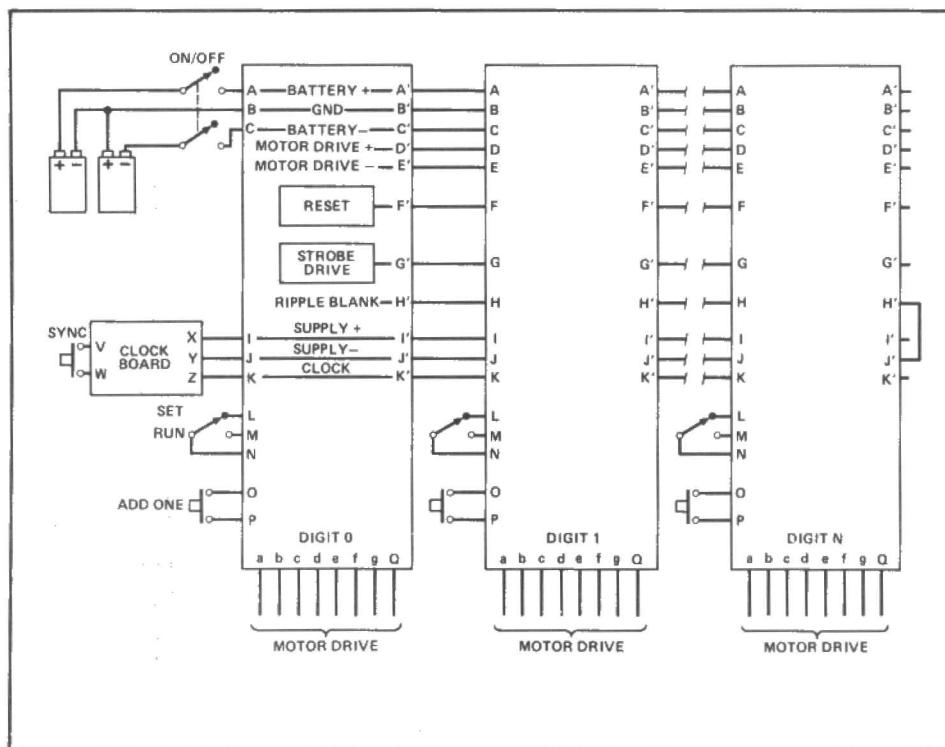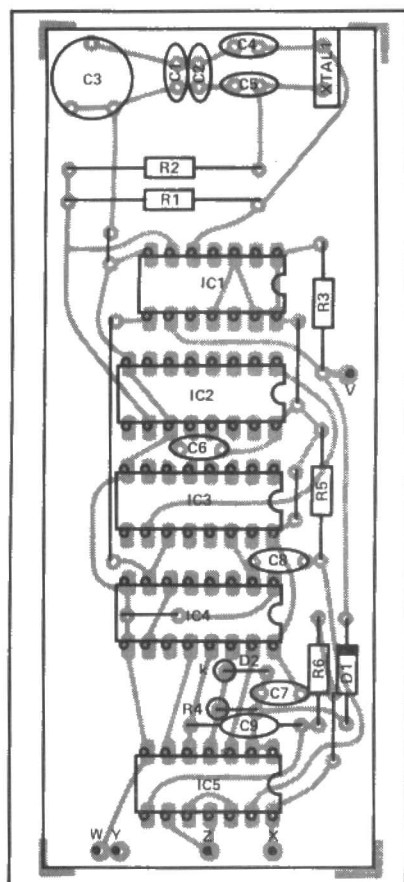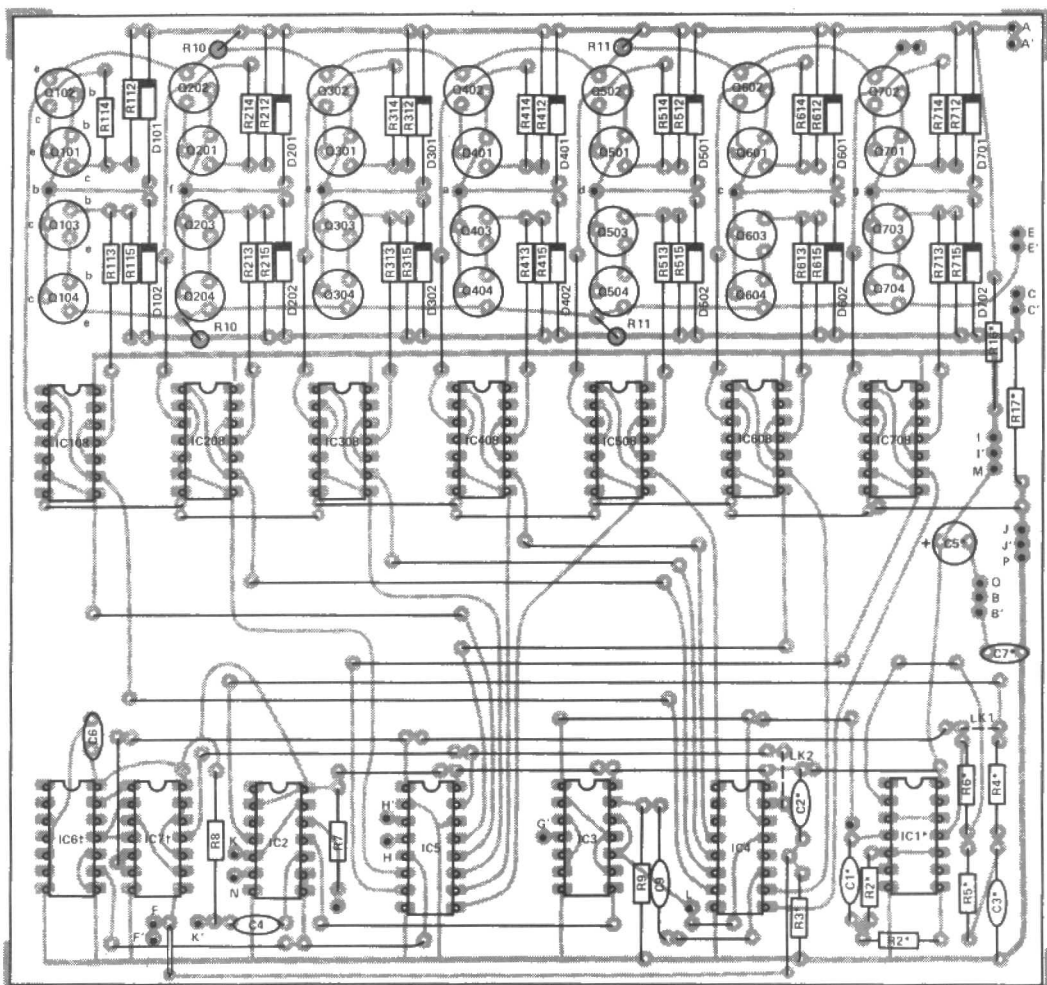
Fig. 8 (left) The component overlay for the minute board and Fig. 9 (above) inter-connection of boards to form a complete display.

ETI

ETI CONCEPT

Robert Stevenson has built what has to be the ultimate mains controller project.

There are a number of mains controllers on the market and indeed many have appeared as projects in the pages of electronics magazines such as ETI.

However, the ETI concept is different. As well as comparing favourably with the cost of commercial devices, the Concept (COst meter aNd Computerised Electronic Programmable Timer) has many extras.

This device is based around a timer with four output channels, each programmable with up to seven on and off times to occur on any day of the week. A 'countdown' facility turns on or off an output after a preset time of between 1 and 99 minutes.

A software lock is also provided. This disables all normal keyboard functions until a programmable four digit 'PIN' number is entered.

A battery-backed RAM memory stores the software key, the programmed times and so forth.

The Concept doesn't even end there. This device also has four isolated digital inputs. When enabled from the keypad, these can overide the programmed switching on each channel.

Unique to such controllers is the Concept's cost measuring facility. The total power drawn by appliances plugged into the Concept can be displayed at any time. The charge rate is programmable and so the accumulated cost or the projected cost for that usage over a period of a day or a week can also be calculated and displayed.

Design Considerations

The initial design used no CPU. It consisted of a CMOS counter circuit with a DIP switch programmed rate multiplier and a couple of op-amps.

Although this was a potentially workable design, the cost seemed out of proportion to the facilities. A timer facility seemed the answer. Although basing the circuit around a timer
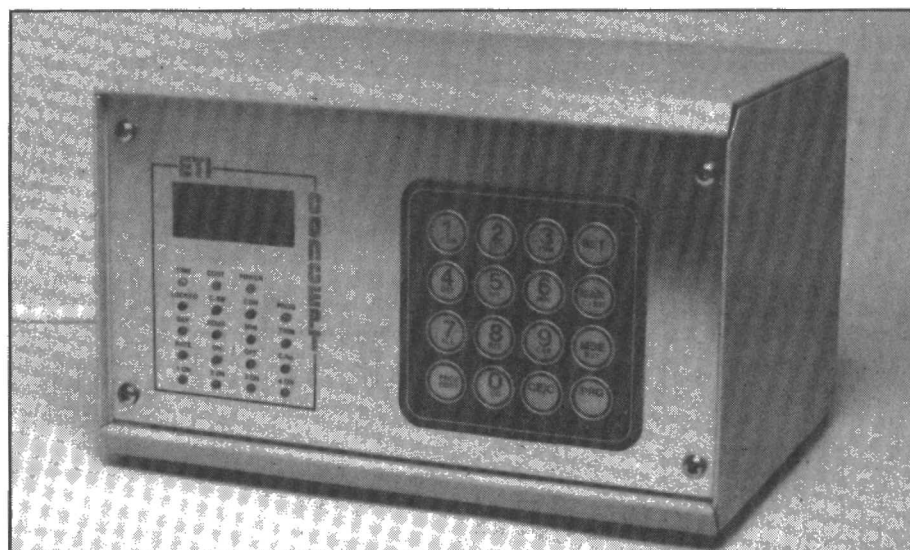
IC such as the TMS1121 is straightforward enough, cost and simplicity demand the timer and cost circuitry share the same display and this complicates matters considerably.

Eventually the Concept was based around a cheap 1MHz 6502 microprocessor and as few peripheral chips as possible.

The power measurement circuitry of the concept is directly connected to the mains. So, for safety reasons two separate power supplies are provided for this and the CPU board.

Multi-tapped transformers are both more expensive and inherrently less safe than two

separate standard mains transformers.

Construction

The Concept is straightforward to build. The major decision required is that of a case. The type used will be partly determined by the front panel arrangement (See Fig. 1) but more so by the number and type of output sockets required. Domestic mains sockets take up a lot of room on the case back panel.

Whatever case is chosen, make sure the two preset resistors on the power board are easily accessable when the whole device is assembled.
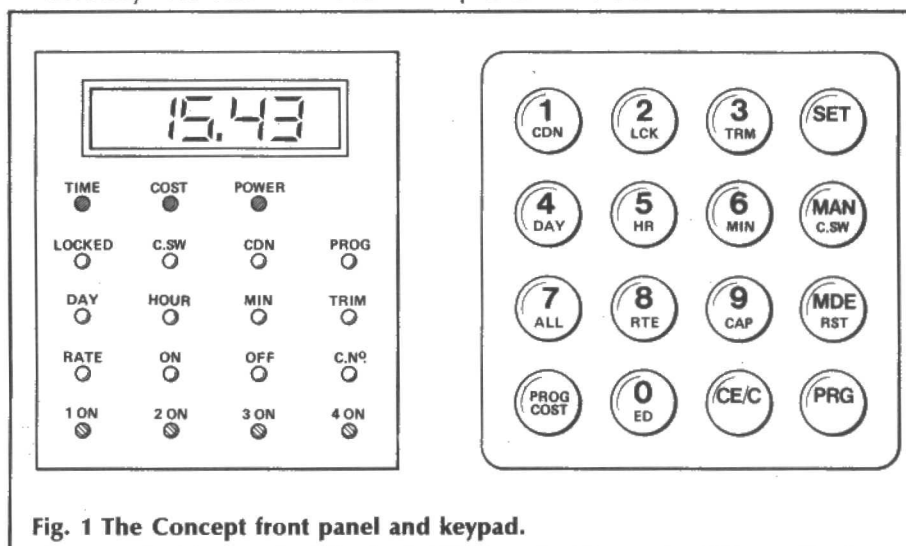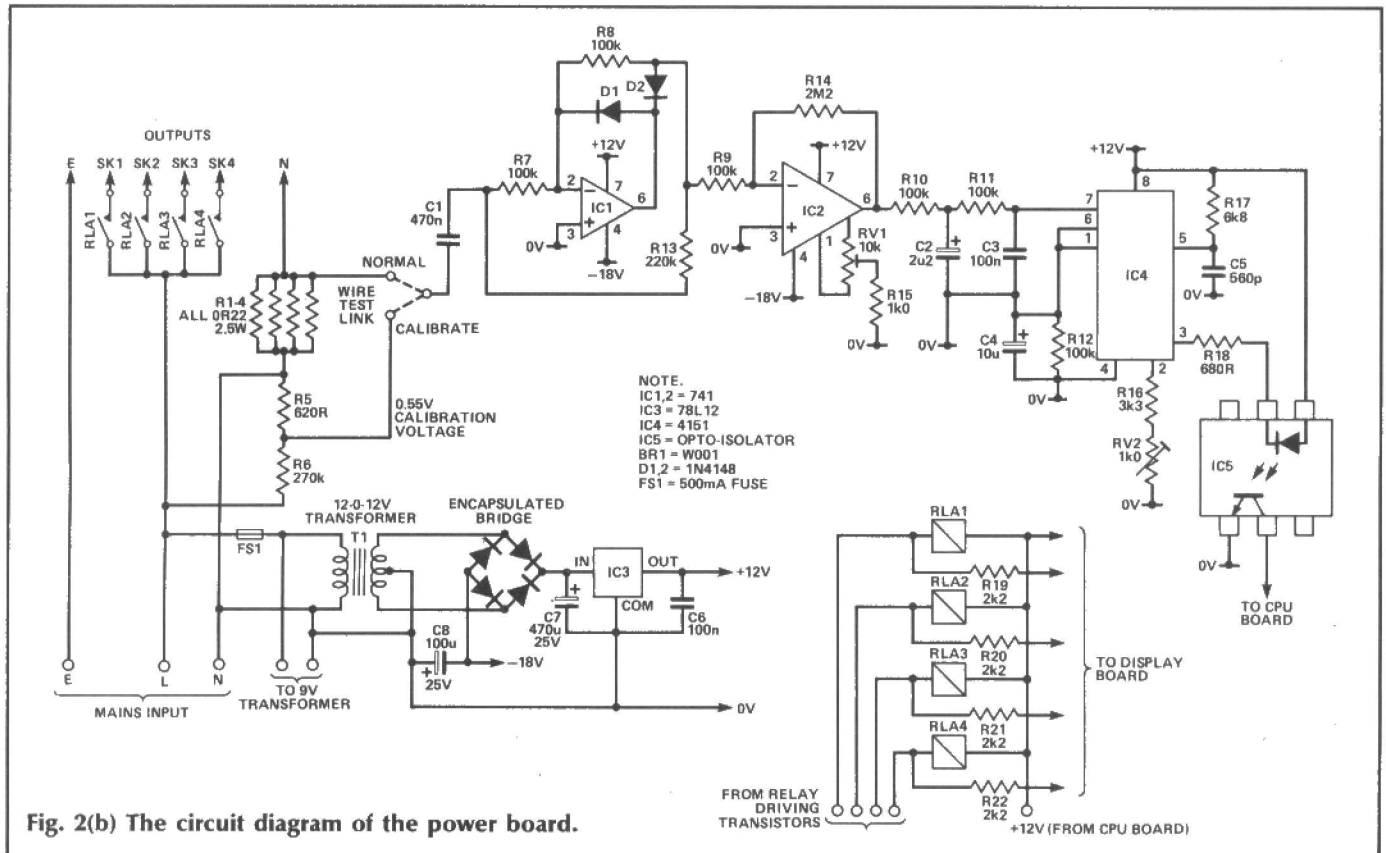

Fig. 1 The Concept front panel and keypad.

Fig. 2(a) The circuit diagram of the Concept CPU and display boards.

Fig. 2(b) The circuit diagram of the power board.

HOW IT WORKS

Figure 2a shows the circuit diagram for the CPU board. The 7805 regulator (IC6) supplies the power. The unusually high value capacitors across the main 5V supply rail and the RAM supply (C7 and C2) ensure that any relay switching surges or mains 'brownouts' do not crash the processor.

The 74LS138 chip (IC5) performs the address decoding. The software resides in a 2764 EPROM which occupies the top 8K of memory. The battery backed RAM is located at the bottom of memory, from &0000 to &0800.

C1, R1, and D6 form a reset circuit that is used by the 6502 CPU and 6522 VIA. The processor requires a 1MHz clock signal and this is provided by IC2 and IC4. IC4a and b form a 4MHz crystal oscillator, the output of which is divided by IC2 to produce the 1MHz signal. The clock input of the 6522 is taken from the CPUs anti-phase clock output $\phi 2$ (pin 39).

The RAM select line from IC5 is ORed with a SUPPLY AVAILABLE signal derived from the transistor circuit of Q1. This OR gate arrangement ensures that the $\overline{CE}$ input of the RAM is held high when the main 5V supply rail is switched off. This puts the RAM in standby mode and prevents memory corruption.

D1 is a germanium device rather than a silicon type because it has a lower forward voltage drop which allows the RAM to work at very near the same voltage as the rest of the memory and provides an optimum charging potential for the NiCd battery.

The current consumption of the RAM and IC11 is very small — when fully charged, the NiCd battery has the capacity to preverve the contents of the RAM for at least a year.

The relay-driving transistors (Q8-11) are switched by the lower four outputs of an eight bit addressable latch 74LS259 (IC7). Diodes D2-D5 protect the transistors from inductive spikes when the relays are switched off.

The multiplexed LED display is driven by another addressable latch (IC8) via six transistors (Q2-7) which supply current to the common anodes.

The cathodes are connected via 47R resistors to IC9, which is an 8-bit D-type latch. The software latches a bit pattern into IC9 then switches on the appropriate anode driving transistor. Every 5ms the transistor is switched off, a new bit pattern is latched and the next transistor is turned on.

The 6522 VIA chip is the Concept's only input IC and it is used to generate interrupts which among many other things, form the basis for the software's real time clock.

The software contains a large proportion of interrupt service code, of widely varying priorities. The real time clock is the highest priority, followed by the display multiplexing routines. Lower priority routines include checking the programmed timer memories and scanning the inputs from the conditional switching port.

The keyboard is connected to the VIA I/O port A. Four lines of port B (PB0-PB3) are connected to the conditional swit-ching socket SK1. Most 6522 applications utilise port B as a simple I/O port but the VIA has an internal counter which can be configured to count down every time PB6 is pulsed low. The Concept utilises this feature to provide a means of mea-suring the frequency of pulses from the power measurement circuitry. The freq-uency is directly proportional to the power consumption of the appliances connected to the Concept. The pulses come from an opto-isolator on the power boards (Fig. 2b). R26 pulls up the open collector of the isolator, and IC4f converts the signal to TTL specifications.

Power consumption is determined by measuring the AC current being sup-plied to the appliances. A very low value resistor, consisting of four 0.22R resistors in parallel, is connected in series with the neutral lead. The voltage drop across this resistor is amplified and precision rectified by two operational amplifiers, ICI and IC2. The output from the second amplifier is smoothed by R10, C2, R11 and C3.

RV1 provides a fine offset adjustment to zero the output and compensate for any circuit noise.

The smoothed output voltage, which varies from about 1mV to 5V, is connected to a voltage-to-frequency converter, IC4. The open collector output from this device is used to drive the opto-isolator. RV2 is used to calibrate the converter. Calibration sets the full scale frequency of the converter to ten times the power consumption in watts so a power consumption of 3000W produces a frequency of 30kHz.

All the internal mains wiring should be rated at 10A at least. The power measurement circuitry of the Concept can cope with the full 13A available from a standard domestic mains socket. Do not use PCB pins for connection of the mains wiring to the power board. These are not designed for these kind of currents. Solder the wire directly to the PCB track.

It is a good idea to use many colours of wire for all the internal connections (both mains and signals) and to approach the whole wiring process in a logical, planned manner.

Some tracks on the power board (Fig. 3) may carry very high currents. You should therefore tin the whole board with copious quantities of solder. The tracks requiring special attention are the thick ones connecting the 0.22R resistors (R1-4), the common live connection to the relay and the live output from each relay.

As the power board carries live mains voltages when plugged in, it is recommended that a piece of insulating plastic is stuck in place over the fuse (but not too firmly — you may have to replace the fuse!).

If you want only the timing facilities of the Concept (what a waste!) omit the power board altogether and use an alternative method of mounting the relays.

If less than four outputs are required, the relevant relays, LEDs and so forth can be omitted. However, it is worth keeping all the relay driver transistors as the 'unused' ones can be connected to another relay to increase the number of programmed times per output.

Fig. 3 The power board component overlay.

PARTS LIST — POWER BOARD

RESISTORS (¼W 5% unless specified)

R1-5	0.22R 2½W
R5	620R 1%
R6	270R 1%
R7-12	100k
R13	220k
R14	2M2
R15	1k0
R16	3k3
R17	6k8
R18	680R
R19-22	2k2
RV1	10k horiz. preset
RV2	1k0 multiturn preset

CAPACITORS

C1	470n polyester
C2	2µ2 16V radial electrolytic
C3,6	100n ceramic
C4	10µ 16V axial electrolytic
C5	560p polystyrene
C7	470µ 25V radial electrolytic
C8	100µ 25V radial electrolytic

SEMICONDUCTORS

IC1,2	741
IC3	78L12
IC4	4151
IC5	6 pin opto-isolator
BR1	W001
D1,2	1N4148

MISCELLANEOUS

FS1	500mA fuse and PCB mount holder
RLA1-4	12V 16A relay
SK1-4	13A 3 pin mains sockets
T1	12-0-12 3VA PCB mount mains transformer

PCB; connecting wire; mains cable; nuts and bolts.

PARTS LIST — CPU & DISPLAY BOARDS

RESISTORS (¼W 5%)

R1-7	10k
R8,9	470R
R10-19	2k2
R20	5k6
R21	1k5
R22-25	1k0
R26	6k8
R27-34	47R

CAPACITORS

C1,2	10µ 10V tantalum
C3	10n ceramic
C4	1000µ 25V radial electrolytic
C5,6	100n ceramic
C7	220µ 16V radial electrolytic

SEMICONDUCTORS

IC1	6502
IC2	74LS74
IC3	2764 EPROM
IC4	74LS04
IC5	74LS138
IC6	7805
IC7,8	74LS259
IC9	74LS373
IC10	6116
IC11	74HC32
IC12	6522
Q1-11	BC548
LED1-2	common anode dual 7-segment digit display
LED3-5	green LED
LED6-17	red LED
LED18-21	yellow LED
BR1	W01
D1	OA47
D2-6	1N4148

MISCELLANEOUS

PAD1	16 key switch pad
T1	9V 20VA mains transformer
XTAL1	4MHz crystal
SK1	5 pin DIN socket
B1	3.6V PCB mounting NiCd battery.

PCBs; case; connecting wire; keypad connector; IC sockets; T05 heatsink for BR1; nuts and bolts.
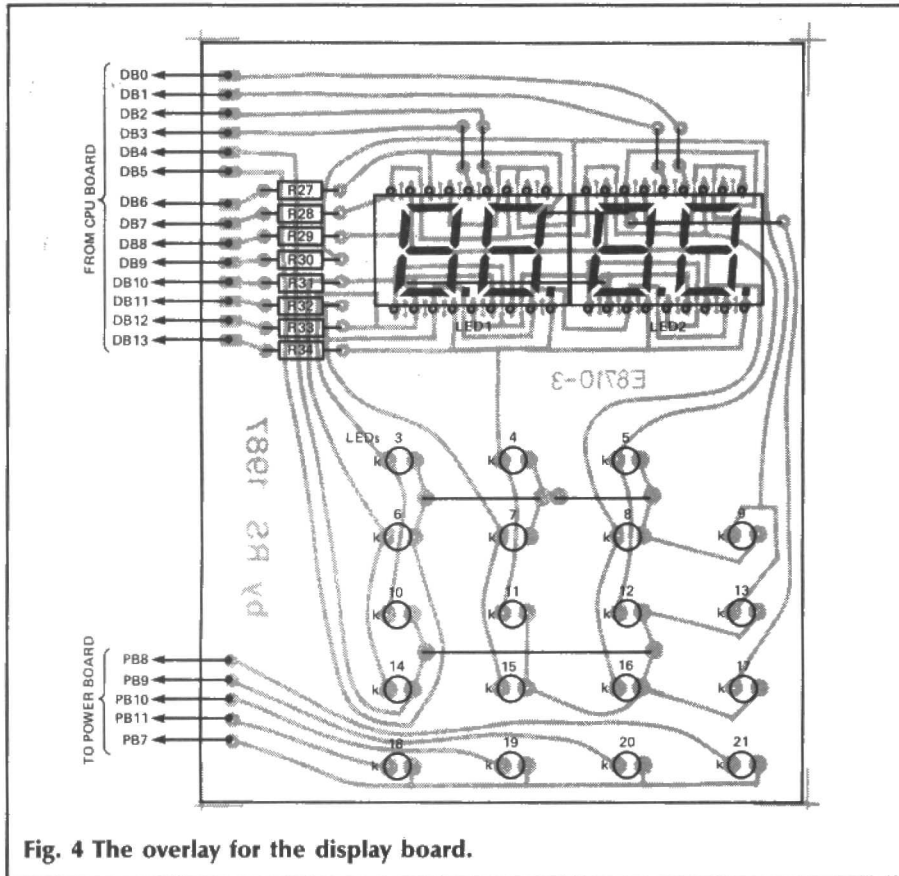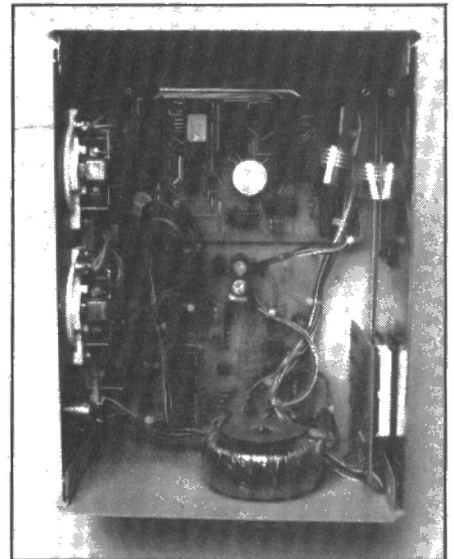
Fig. 4 The overlay for the display board.

The insides of the Concept prototype. Panel mounting mains sockets were chosen for the prototype because they take up less room on the back panel than normal pattress-mounting sockets. Alternative design, non-standard sockets could also be used to make the Concept more compact. Make sure the two calibration preset pots on the power board (RV1 and RV2) are easily accessible when the whole unit is assembled, as they are here.

Fig. 5 The CPU board overlay.
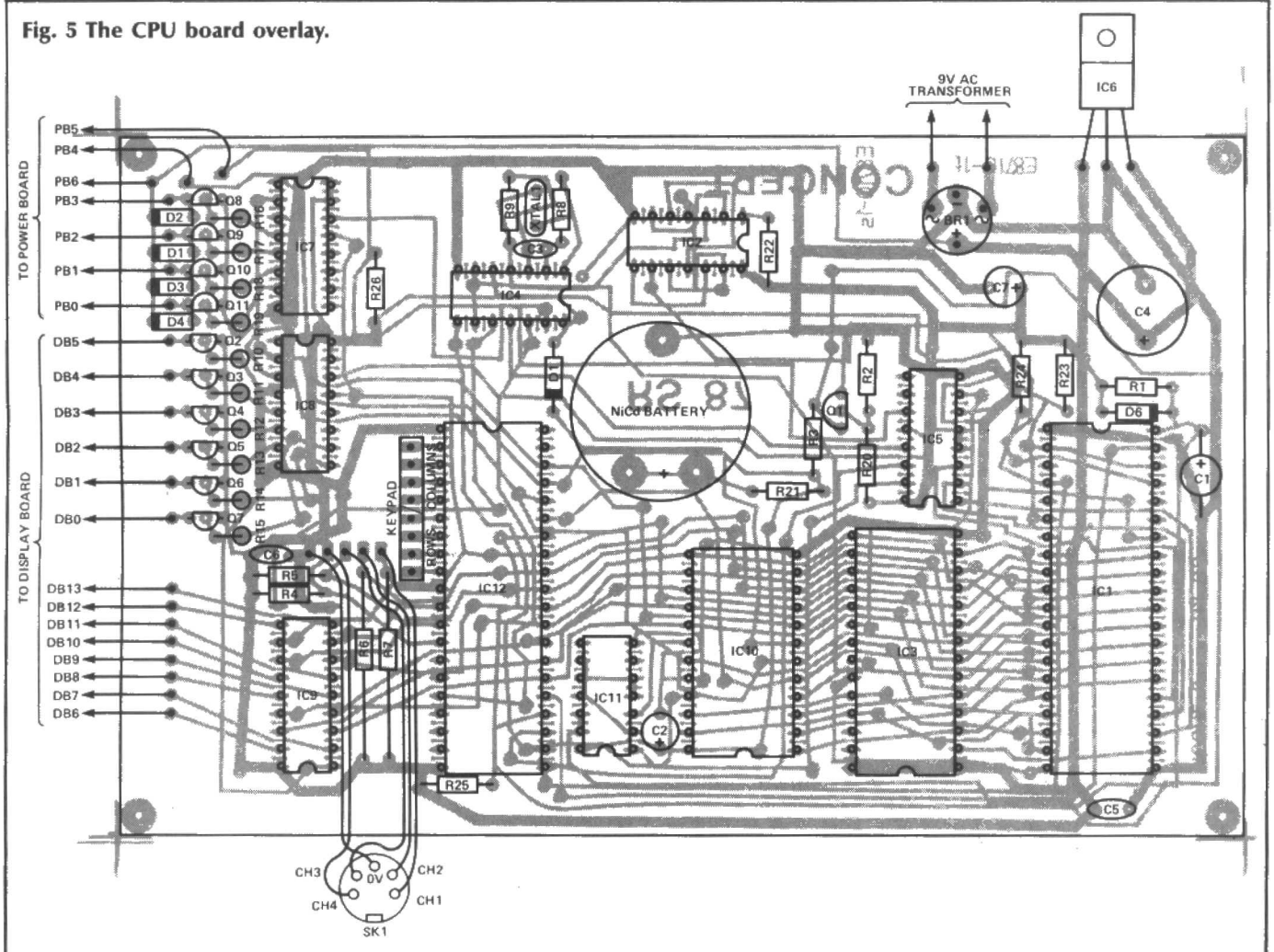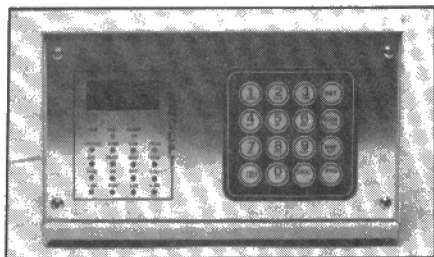
The display board (Fig. 4) contains the 19 display LEDs and the two dual digit 7 segment displays. The latter should not be directly soldered to the board but mounted in 'soldercon' type sockets.

Note that three links are required underneath the digital displays and should be soldered in first of all.

Solder all the LEDs at the same height above the board. The case should have a rectangular cutout for the digital display and 19 holes drilled for the LEDs. The display board will then sit in position, largely held there by the LEDs.

The CPU board (Fig. 5) is double sided and requires through connection pins. Some through connections are made by the leads of components. Look at both sides of the board as you solder in the components and if a pad is provided on both sides of the PCB, solder both sides.
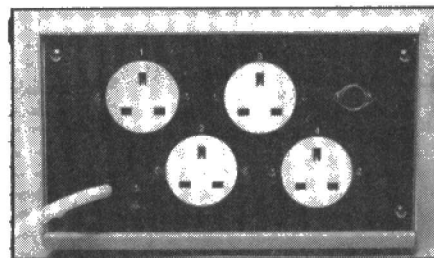
Note that all the ICs, electrolytics and other polarised components are *not* orientated the same way. Take care and check before soldering.

The 5V regulator (IC6) must be fitted with a good heatsink or bolted to the (metal) case. A blob of heat transfer compound is also recommended.

The final component to install on the CPU board is the EPROM (IC3). This can be either a 2764 or 27128 and an IC socket should be used. The EPROM should, of course, be first programmed with the Concept's operating system. Programmed EPROMs are available from the author (see Buylines). The hex dump of the EPROM and calibration and operation details will be given next month.

ETI

BUYLINES

Despite its complexity, the vast majority of the components used in the Concept are easily available from usual sources.

The prototype used case 501-597 from Electromail (Tel: (0536) 204555). The PCB mounting transformer for the power board also came from Electromail (part 207-835) as did the relays (part 346-269).

Any 4x4 keypad may be used or one made up from individual key switches.

The PCBs are available from the ETI PCB service. The software is available from the author. A programmed EPROM is available for £15. A BBC micro disk (specify 40 or 80 track) containing the source and object code also costs £15. Both EPROM and disk cost £20. Please address all orders and enquiries to Robert Stevenson, 229 Vicarage Road, Leyton, London E10 7HQ.

HYPER-FUZZ

Not another fuzz box! 'Fraid so but Charles Dancer's design brings a whole new meaning to distortion effects.

The Hyper-fuzz is a new type of distortion effect which should be of interest to musicians who like to experiment with the sound of electric and electronic instruments.

Distortion or fuzz units are used to make the sound of a musical instrument more 'interesting' by adding harmonics to it. This is usually achieved by using a non-linear amplifier of some kind to clip or round-off the peaks and troughs of the audio signal. The resultant distortion consists of a wide range of harmonics at multiples of the input frequency.

The input/output characteristic of the Hyper-fuzz is shown in Fig. 1. Each half-cycle of the audio signal is 'folded over' three times before being clipped. This gives rise to a narrow band of harmonics, the frequency of which is dependent on the amplitude of the input signal. When used with a guitar a filter-sweep effect is produced as each note dies away.

In addition, the circuit can produce conventional clipping distortion and an intermediate effect, selected by a three position toggle switch, SW1. These extra characteristics are also shown in Fig. 1.

The circuit board is mounted in a small diecast box fitted with a foot switch (SW2) which is used to switch between the effect and a 'straight through' signal. A metal box was chosen in preference to a ready-made foot switch case because of it's lower cost and better screening properties. The other controls on the unit are DEPTH (RV1) which varies the severity of the distortion, and LEVEL (RV2) which is used to match the distorted and straight-through signals in volume.

Power for the effect comes from a PP3 battery, or from an external 9V supply, the current consumption being only about 2mA. The internal battery is connected when a jack is plugged into the input socket, so there is no need for an on/off switch.
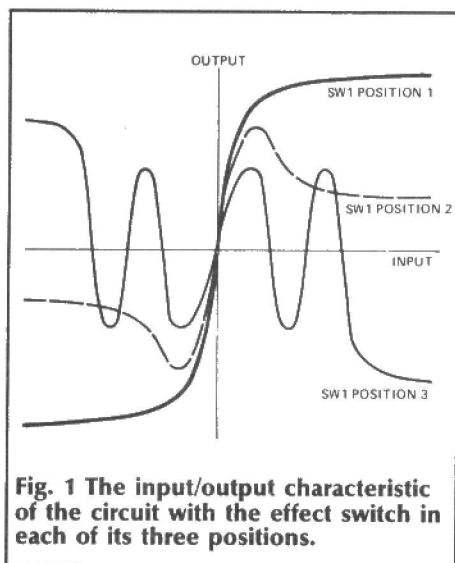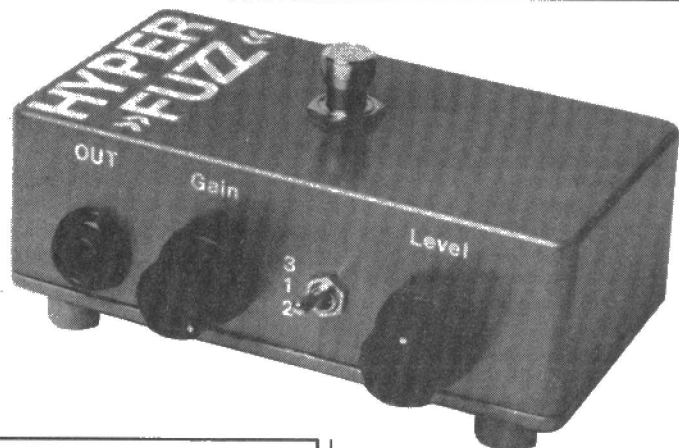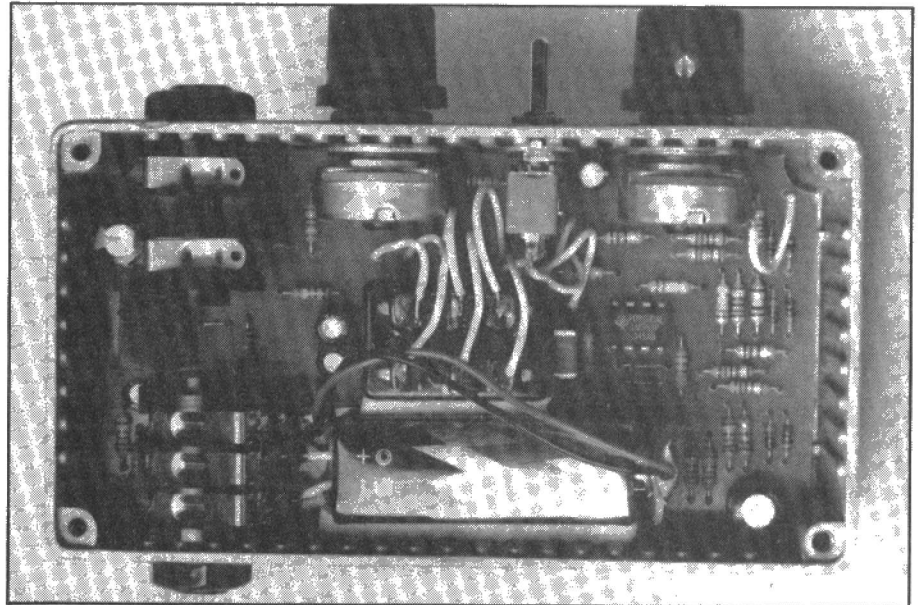

Fig. 1 The input/output characteristic of the circuit with the effect switch in each of its three positions.

Construction

If the recommended case is used, it should be drilled as accurately as possible as shown in Fig. 3. The positioning of the holes is fairly critical. The PCB should be assembled (Fig. 4) starting with the smaller components ensuring that all leads are cropped close to the board.

When the two pots are mounted, their spindle centres should be about 15mm above the top of the PCB.

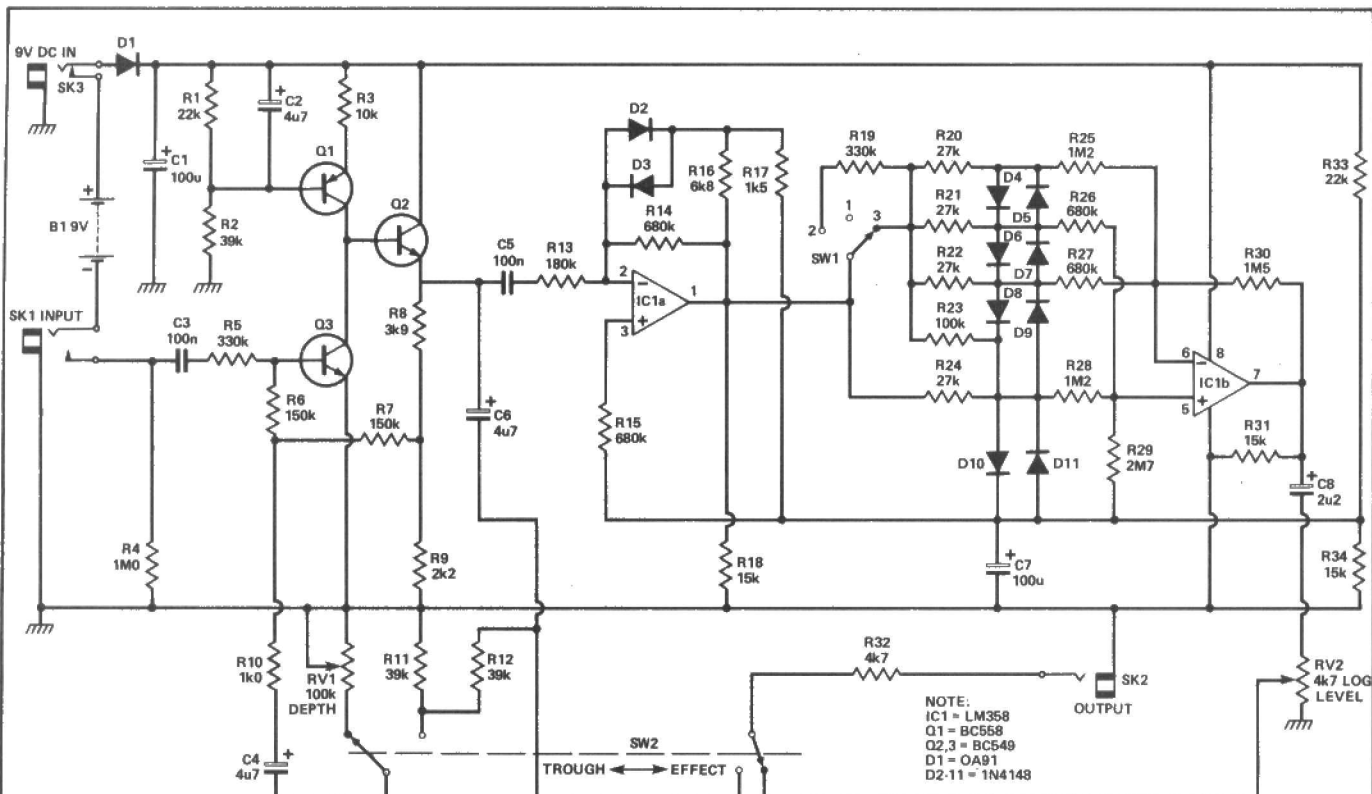If the jack sockets have break contacts fitted, the tags for these

Fig. 2 The circuit diagram of the Hyper-Fuzz.

NOTE:
IC1 = LM358
Q1 = BC558
Q2,3 = BC549
D1 = OA91
D2-11 = 1N4148

──HOW IT WORKS──

The input signal is fed to a pre-amplifier comprising Q3, which provides the gain, a constant current source (Q1), and an emitter-follower (Q2) to buffer the output. With SW2 in the 'Through' position, the gain of the pre-amp is set at about one by negative feedback through R10 and R6 and its output goes to the output socket (SK2) via C6. With SW2 switched to 'Effect', RV1 is used to vary the amount of feedback and hence the gain of the pre-amp.

The distortion-generating part of the circuit uses an LM358 dual op-amp, which was chosen because of its low current consumption and wide output voltage range. R33/34 and C7 provide a stable 3.5V mid-rail for the op-amps. The signal from the pre-amp is further amplified by IC1a. The op-amp is prevented from clipping by D2 and D3, which limit its output to about 6V peak to peak. With SW1 in position 3, the output of IC1a will drive the four pairs of diodes, D4-11, to produce four waveforms clipped at ± 0.5, 1, 1.5 and 2V. These are then fed to alternate inputs of a difference amplifier (IC1b). So, as each diode begins to conduct, the gain of the circuit reverses polarity.

With SW1 in position 1, only the lower pair of diodes is driven, so the circuit produces 'ordinary' fuzz. For the intermediate effect, R19 is used to attenuate the signal reaching the upper diodes. R23 is necessary to match the three effects in volume.

should either be cut off or bent under the socket. The sockets should then be attached to the board by 15mm lengths of flexible wire. The toggle switch and RV2 case can then be connected to the board along with the battery clip and six 45mm pieces of wire, for the foot switch.

The PCB spacer is a piece of 4mm thick perspex, wood or paxolin, 22x26mm, with a ½in central hole. To make assembly easier the spacer can be lightly glued to the track side of the PCB. Before the unit is assembled an insulating grommet should be fitted to the hole for the power connector.

The PCB assembly can then be inserted into the case. To do this, the output jack and the two pots should first be located in their respective holes (the pots may need to be bent back a little).

Once the pots are pushed through, the board should fit neatly inside the case and the other socket and toggle switch can then be fitted. The foot switch should be fitted through the holes in the board, spacer and case so that it holds them together, and it's leads soldered as shown on the component overlay.

If you intend to drill the base plate to take screw-mounting feet, make sure that the screws will not interfere with the jack sockets. With care, they can be positioned so that the feet slightly overlap the retaining screws, thus preventing them getting lost. The battery can be cushioned using strips of draught excluder stuck inside the case and on the side of the switch, and held in place by a piece of foam rubber glued to the base plate.
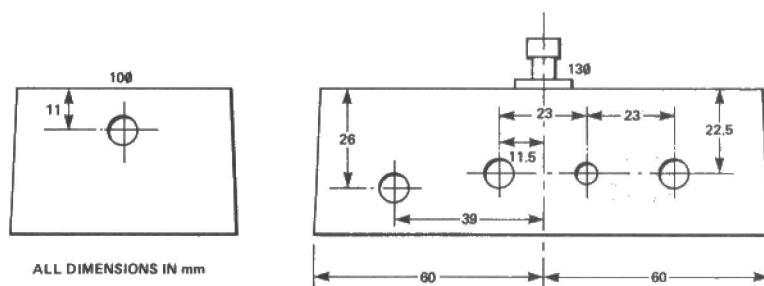

ALL DIMENSIONS IN mm

Fig. 3 Drilling the case for the Hyper-Fuzz.

Fig. 4 The component overlay.

PARTS LIST

RESISTORS

R1,33	22k
R2,22,12	39k
R3	10k
R4	1M0
R5,19	330k
R6,7	150k
R8	3k9
R9	2k2
R10	1k0
R13	180k
R14,15,26,27	680k
R16	6k8
R17	1k5
R18,31,34	15k
R20,21,22,24	27k
R23	100k
R25,28,30	1M5
R29	2M7
R32	4k7
RV1	100k lin PCB mounting
RV2	4k7 log PCB mounting

CAPACITORS

C1,7	100µ 16V radial electrolytic
C2,4,6	4µ7 63V radial electrolytic
C3,5	100n polyester
C8	2µ2 63V radial electrolytic

SEMICONDUCTORS

IC1	LM358
Q1	BC558
Q2,3	BC549
D1	OA91
D2-11	1N4148

MISCELLANEOUS

SW1	SPDT centre-off toggle
SW2	DPDT foot switch
SK1	¼in stereo socket
SK2	¼in mono socket
SK3	2.1mm power socket (PCB mounting)

PCB; case; battery clip; knobs; feet; PCB spacer; ⅜in grommet; foam rubber; M10 washers.

BUYLINES

All the components are available from Maplin with the exception of the LM358. This is stocked by Technomatic and other major suppliers.

The case used in the prototype (Type 5004, 120x65x40mm) is available from Maplin as part LH71N.

The PCB is available from our PCB Service. See the back of this issue for details.

Operation

The unit should be set up in the same way as a standard distortion unit. Adjust RV1 and SW1 until the desired effect is heard, then adjust RV2 so that there is little change in volume when the foot switch is pressed. Because of the severity of the distortion, the full Hyper-fuzz effect (Setting 3) works best with simple 'pure' signals. Playing chords produces harsh ring-modulator-like effects which are interesting but not exactly musical. Although the unit was designed for use with electric guitar and bass, it can also be used to alter the sound of keyboard instruments, drum synthesisers and even vocals. **ETI**

THE ETI EEG MONITOR

Paul Chappell continues his alpha training with a look at how to put last month's monitor to good use.

Having built the brainwave monitor last month and admired the sound of your alpha rhythms, you're no doubt wondering — what next? This isn't the kind of project where we can just leave you to your own devices so this month I'll be talking about various ways the monitor can help you to improve your mental powers and feel good.

I will also be going into more detail on the subject of electrodes. Last month I gave some fairly detailed instructions for making them but didn't explain why the process was necessary. If you've tried blobs of damp cotton wool on the end of croc clips or some such short cut, you will have discovered for yourself that it doesn't work. But why not?

This is not a 'lego' project, to borrow J. Bird's infamous phrase. Although you can probably get by if you follow the instructions to the letter a 'feel' for what's going on will help you get the best results from your monitor and to sort out any problems that may arise. All will be revealed.

Improvements And Additions

The first experimental circuit was built way back in January but I have become rather obsessed with brainwaves and EEG and I have used the monitor intensively over the past month. There are a few minor modifications and additions I have made to the prototype that you may find useful.

When I designed the filter section of the monitor my aim was to make it as solid and reliable as possible and to avoid the need for 'tweaking'. The circuit exceeded my expectations in this respect but one little niggle was the inclination of the filter to become excited by background activity, causing a certain amount

of 'burble' to the sound.

Both filter sections are resonant, which means that they have a tendency to be stimulated by transients, rather like a pistol shot echoing round a bathroom. (I've never heard one but I can imagine what it's like!) Since the filters perform very well in other respects I was reluctant to change them and eventually hit upon the simple solution of interposing a pair of anti-parallel diodes between IC4 pin 8 and C15.

Although it's most annoying to have to hack a perfectly good PCB about, the surgery in this case is quite minor. Since C15 and C16 are next to each other on the board, with C16 being fed first, it's just a matter of cutting the track between them and soldering the diodes to the back of the board (Fig. 1).

The improvement is well worth the effort! If you make your own PCB, you may prefer to alter the tracking to accommodate the extra diodes — there's plenty of room.

Although the filters don't really need any 'tweaking', perfectionists may like to tune up the value of R24 for best interference rejection.
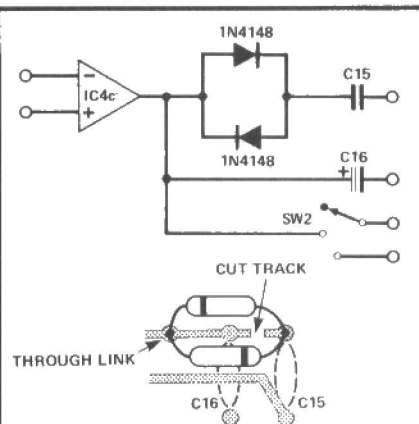
Fig. 1 A modification to cut down background noise.

Replace it temporarily with a 27k resistor in series with a 10k preset. Dangle the electrode leads over the bench top to pick up the CEGB's free test signal (mains hum), set 'direct' mode and 'beta' on the controls, turn up the gain and adjust the preset for minimum 'burble'. There will be a certain area of rotation where the burble decreases dramatically. Set the preset to the centre of this area, then take out the resistor and preset and measure the combined resistance on your
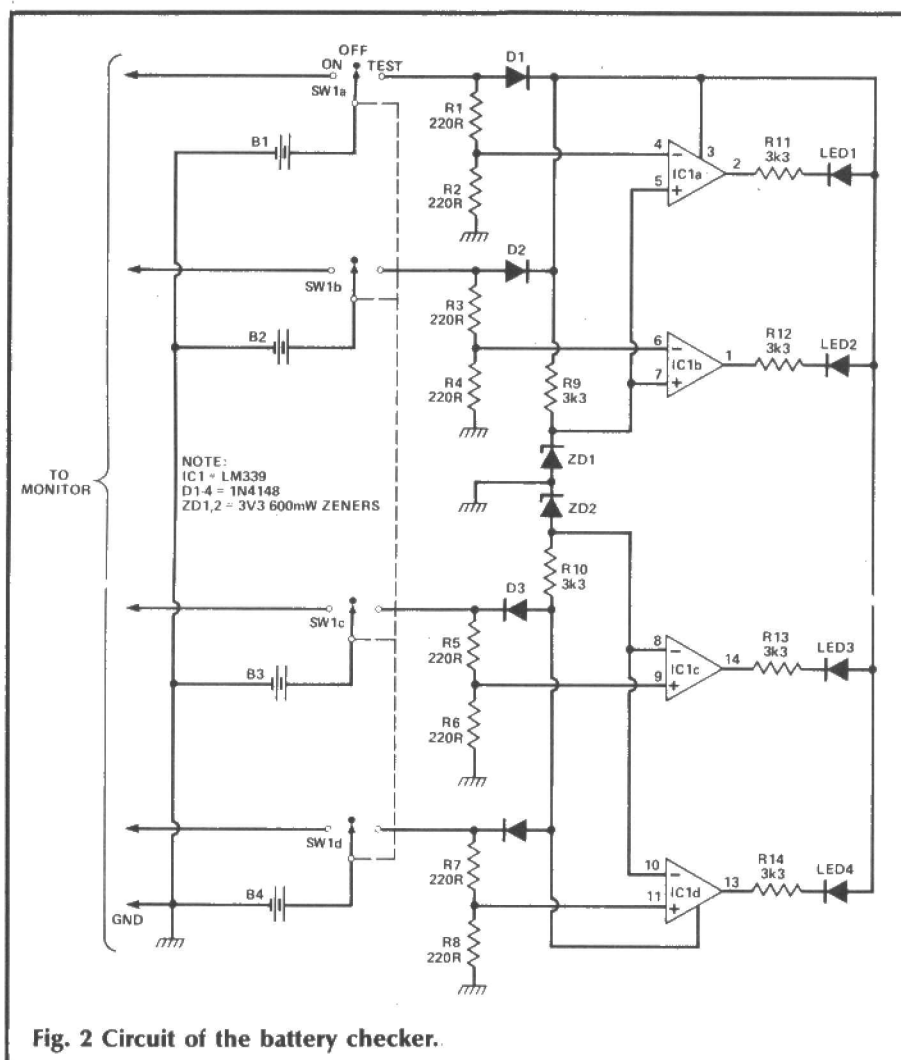
Fig. 2 Circuit of the battery checker.

NOTE:
IC1 = LM339
D1-4 = 1N4148
ZD1,2 = 3V3 600mW ZENERS

'on', 'off' and 'test' functions. You may prefer to wire the 'test' between the 'on' and 'off' positions to give a check on the batteries every time you use the monitor. Since there is very little room on the front panel, the circuit will have to join the switch at the back.

Electrodes

The electrodes are the most critical part of the monitor. If you have built it and find that the circuit is working (touching the input with a finger gets it all excited, for instance) but it won't register your brainwaves, the problem is almost certainly the electrodes.

Dry electrodes are unsuitable for most bio-monitoring purposes. You can get an idea of the contact resistance between dry electrodes and skin by grabbing the terminals of your multi-meter on a high resistance range. A resistance of 10k between any two electrodes is considered to be just on the borderline of acceptability for EEG purposes and you'll find from experience that interference and noise will increase enormously if this is exceeded. There is also the question of the chemical effects of sweat on the metal and the mechanism of conduction of tiny currents (around 10pA for EEG signals).

Some form of metal to liquid contact is always involved — either from a deliberately introduced electrolyte in the case of surface electrodes or from body fluids in the case of 'needle' electrodes, which are inserted under the skin, or other types which are implanted in the brain (and are outside the scope of this project!)

Electrode potential

When an electrode is in contact with an electrolyte, a difference in potential is developed between the metal and the solution. If you think about it for a moment, you'll see that's it's impossible to say exactly what this voltage is. The only way to measure it would be to insert another electrode to measure the voltage of the solution and you end up measuring *that* electrode's potential too!

A hydrogen electrode (usually hydrogen dissolved in a platinum compound) is arbitrarily taken to represent 0V and other electrodes are measured with respect to this.

In theory, two electrodes with the same surface material should end up at the same voltage with

multi-meter. Find a resistor which gives the same reading and solder this in the R24 position. This process should be carried out *before* fitting the two extra diodes.

A small workshop tip: when using a multi-meter to compare resistances, it's best not to have too much faith in the readings. A factory fresh analogue multi-meter will rarely give better than 5% accuracy on resistance ranges and unless it is re-calibrated regularly the chances are it will be much worse. By using the meter to compare resistors directly you rely on the meter's repeatability (how closely the two readings match when the same resistance is connected on two different occasions) which will be much better than its accuracy. Choosing two resistors which give the same scale reading will probably match them to within 1% although you may not know the actual value even to within 5%! Digital meters give the illusion of great accuracy by giving readings with several significant figures. When they leave the factory they are often very accurate but after a year....

For safety it is essential to power the monitor from batteries. Having found that everybody who set eyes on it wanted to have a go at developing their alpha and theta rythms and with a set of alkaline batteries costing near on £8, the upkeep soon became rather expensive! One thing I quickly stopped doing was throwing away all four batteries at once. Some would still be perfectly OK when others were completely flat. To save the bother of taking them out and testing them, I built a simple battery checker (Fig. 2).

If the voltage of any battery drops below about 6½V on load, the corresponding LED will not light. The circuit takes its power from the two healthiest batteries, which also have the burden of the LEDs, so the weakest batteries are loaded by the two 220 ohm resistors which draw about 15mA when the LED is at the point of turning off. If they can't cope with this, they're ready for the bin.

The on/off switch on the original circuit is replaced by a 4-pole 3-way rotary switch, giving

respect to the solution, so the voltage between them should be zero. In practise, variations and impurities in the surface of electrodes will always result in a voltage difference between them and one reason for choosing one electrode material over another (but not the only one!) is the stability of its potential. Silver-silver chloride electrodes are better than most in this respect.

The monitor can cope with a maximum voltage difference between the two sense electrodes of about 5mV. If your monitor appears to be 'dead' it is almost certainly because the electrode potentials are too far apart.

There are two ways to get around this problem. The preferred one is to take great care with plating and chloriding the electrodes and to store them in a way that will maintain them at the same voltage.

The chloriding process using household bleach works fairly well (and was recommended by a hospital EEG technician!) but for the perfectionists there is another way to go about it. You'll need some de-ionised water (sold in car shops for topping up batteries. It's often called 'distilled' water but you can bet your life it isn't) some sodium chloride (analar grade) from your chemist (table salt is not pure sodium chloride — it contains other compounds to help it flow freely), a piece of silver wire (any jewellers shop with a repair department should be able to sell you some).

Make up a weak saline solution — between 2- 5g per 100ml of water. Pour some of the solution into a suitable container (a small cereal bowl will do) to a depth of about ½in. Dip the business end of the electrodes into the solution, keeping the stems dry.

The chloriding is best done with the muslin bags in place — they will protect the coating. Connect all the electrodes together with wire and crocodile clips (Fig. 3a) and connect to the positive terminal of a battery via a 100k resistor. The negative terminal of the battery connects to the silver wire which dips into the saline solution at the opposite end of the bowl from the electrodes. The electrodes can be cleaned prior to chloriding by reversing the connections for a minute or so.

Chloriding by this process takes about 30-60 minutes and should ideally be done in the

Fig. 3(a) Chloriding the electrodes. (b) Storing the electrodes. A reasonable substitute for a carbon rod would be the lead from a soft pencil.
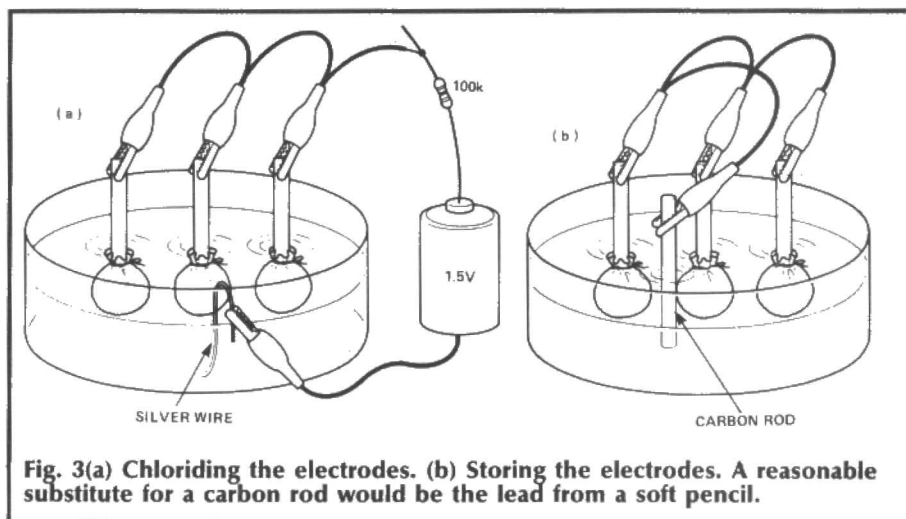
dark since silver compounds are light sensitive. The general rule is the slower the chloriding process, the more even will be the final coating, although beyond a certain level the law of diminishing returns comes into effect. But don't let me stop you using a 1M0 resistor and leaving the electrodes in all night!

The same apparatus can be used for storing the electrodes and keeping them at the same potential. This time, instead of a battery and silver wire, a cabon rod is dipped into the solution. Carbon is slightly electropositive with respect to the electrodes and will maintain just enough current flow to keep the surface in good condition.

Don't forget to top up the water every now and again or you'll find all the electrodes covered with a crusty mess of salt next time you come to use them. If you intend to take this seriously, you might consider making a container with a suitable electrode support and a lid to cut down on evaporation.

The Bodge

The other method for maintaining the electrodes at the same voltage is an electrical 'fix' applied to the monitor. If there is a path to ground, the flow of current will alter the iron concentration around the electrodes and keep them within the monitor's range. Connecting a 1M0 resistor between each input and ground is quite acceptable and the monitor will still work effectively with resistors as low as 100k, which should pull the most stubborn electrodes into line! The resistors can be soldered to the input jack.

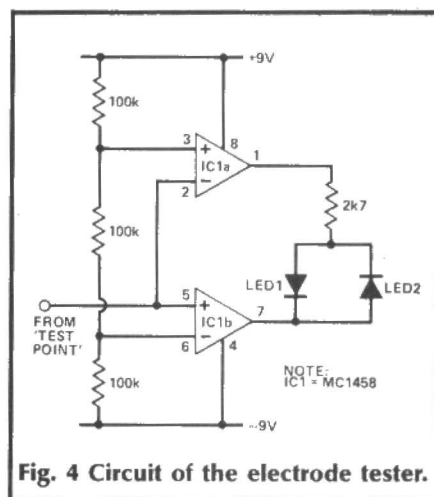A very useful addition to the monitor is a circuit to indicate

Fig. 4 Circuit of the electrode tester.

when the electrodes are within acceptable limits. The circuit is shown in Fig. 4. The input is connected to the output of the bio-amplifier (the 'test point' on the main PCB) and the circuit checks to see that the DC level is within the middle third of the supply range. Both LEDs will be off if all is well, so the additional current drain will be small.

If either LED lights up, the first thing to check is that the electrodes are making good contact. If your hair is in the way, they won't be! If you can't make the LEDs go out by moving the electrodes slightly or parting your hair (and the chances are that you can) then it's time for re-chloriding.

Too much salt solution is no substitute for good electrode positioning. Two adjacent electrodes can easily be sorted out by drips of saline and at best you'll get a confused signal from the whole of the surrounding area and salt solution down your neck!

Electrode Characteristics

Conduction between the saline solution and electrodes takes

place in one direction when chlorine ions combine with the silver to form silver chloride. The chlorine ions carry a negative charge from the solution to the electrode. In the opposite direction, silver chloride dissociates into silver and chlorine ions. The chlorine ions pass into the solution, once again carrying a negative charge. The process is reversible and electrodes of this type are called, naturally enough, reversible electrodes.

There are other types of reversible reaction that can be used. A metal in a solution containing its own ions (tin in stannous chloride or zinc in zinc sulphate, for instance) will give current flow via the cations rather than the anions. Oxidation and reduction of ions with two valence states is another possibility. In practice, the range of chemicals that are actually useful is limited by the substances people would be willing to have on their heads! Stannous chloride and zinc sulphate both cause skin irritation, so would only be considered where there is a pressing need to use the corresponding electrode type. Sodium chloride is cheap, harmless and can be left for long periods without causing irritation, so is the most commonly used electrolyte.

An unfortunate characteristic of some electrode types is the tendency to polarise. If a DC voltage is applied, positive ions migrate to the negative electrode and negative ions to the positive one. A back EMF is developed, which interferes with the signal. To slowly changing signals, the effect is similar to wiring a

capacitor in series with the electrode. On faster signals, with highly polarised electrodes, the effect is almost like rectification since they favour current flow in one direction rather than the other.

Chlorided silver electrodes are relatively immune from polarisation effects (Fig. 5) but it is not a good idea to provoke them by measuring the contact resistance with a multi-meter. Commercial EEG equipment is usually fitted with a resistance checker which applies an AC voltage of a few mV to the electrodes and measures the resulting current. If you have a signal generator and AC current meter, you can follow the same procedure.

Commercial electrodes

You may be interested to know how the electrodes specified for the monitor compare with electrodes which would be used in hospitals or EEG laboratories. Figure 6 shows some of the types in common use. The pad electrodes (Fig. 6a) are similar to the home made electrodes but would normally be made of solid silver. Since it is the surface layer that is important, the only disadvantage of using plated electrodes is the possibility that defects in the plating or wear of the surface will allow the electrolyte to make contact with the metal underneath. If this happens, large, fluctuating potentials can be developed by chemical action so once again I wag my finger at you and say 'Take care!'

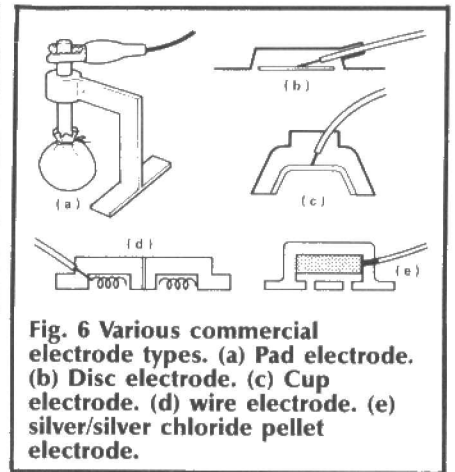Chlorided silver is also available in the form of discs,

Fig. 6 Various commercial electrode types. (a) Pad electrode. (b) Disc electrode. (c) Cup electrode. (d) wire electrode. (e) silver/silver chloride pellet electrode.

cups and wires. For the very stringent requirements of DC recording, porous pellets of silver — silver chloride are used. It is generally agreed that for good recordings and stable bias potentials a large surface area is desirable, and the pellet electrodes have a huge area of contact with the electrolyte.

Apart from surface area, the only other distinction between the electrodes is the way they are held in place. Pad types would normally be fitted to an elastic harness and held against the scalp by pressure. Other types can be held in place by self-adhesive pads or by a type of glue called 'collodion'. Electrodes fixed by collodion will stay in place for long periods but it's very messy stuff to get off afterwards. Usually it is dissolved in acetone, then the final traces removed by a thorough shampooing. Pad types were chosen for this project because they are the easiest to apply and don't need electrode creams or glues.

Because of the difficulty of making good contact on the hairy areas of the scalp, needle electrodes which slide under the skin are occasionally used. They are usually made of stainless steel and give poor recordings. Other types (not recommended for home experiments!) include nasopharyngeal electrodes which are inserted through the nostrils to make contact with the lower surface of the temporal lobe, sphenoidal electrodes which are inserted through muscle tissue, and intercerebral electrodes which are implanted in the brain. Perhaps I'd better not say any more — I don't want to put you off your supper!

Why Worry?

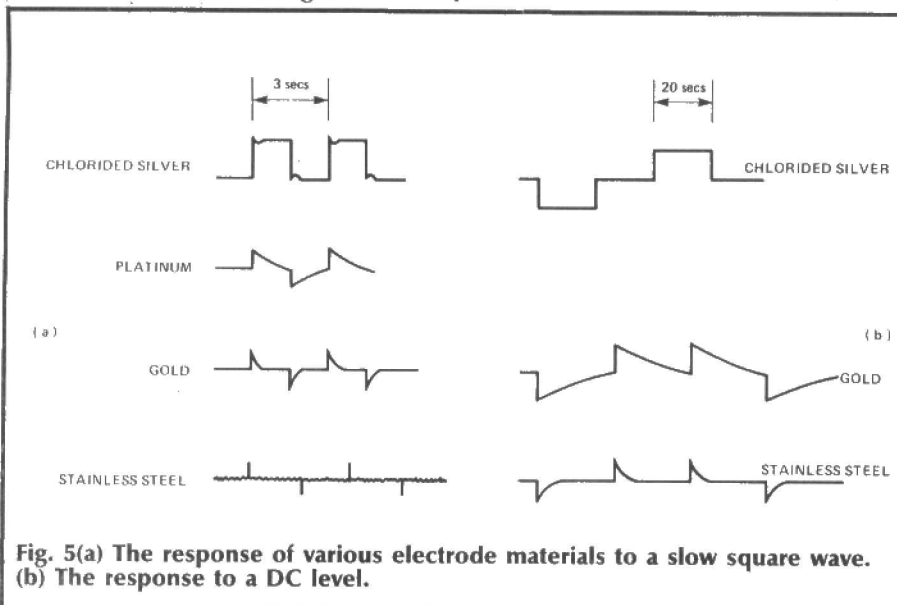If I've made it all sound impossibly complicated — don't

Fig. 5(a) The response of various electrode materials to a slow square wave. (b) The response to a DC level.

worry. The electrode requirements for the monitor are much less stringent than for recording an EEG trace. Most EEG users have favourite electrode types (whatever they happen to be used to) and develop procedures for applying them that owe more to practical experience than to text book theory. You'll probably find the electrodes a bit fiddly to apply the first few times, after that you'll wonder what all the fuss was about. So, don't worry. Worrying spoils the alpha signal!

The Second Step

Last month I described how you might connect up the monitor and wait for your alpha rhythm to arrive. Now it's time to go a stage further and learn to control it!

The first major study to show that voluntary control of the alpha rhythm was actually possible was undertaken by a research psychologist by the name of Joe Kamiya. His results were published in 1969 under the rather forbidding title 'Operant Control of the EEG Alpha Rhythm and Some of its Reported Effects'. Kamiya's research is now very well known and a brief description of his experiments has even appeared in the pages of ETI (Biofeedback Monitor, November 1986). Since it is an excellent introduction to alpha training and something you can easily do yourselves, I'll run through it again.

Kamiya's first aim was to train his subjects to distinguish between the 'feeling' of two different brainwave states. He would connect his subjects to an EEG monitor which he could see but they couldn't. On a signal (the ringing of a bell) his subjects had to say whether they thought they were in state A or state B. Since Kamiya hadn't actually told them what these states were, they had no choice at first but to make a wild guess. He would then tell them whether they were right or wrong. After some time, his subjects would begin to recognise the difference between the two states and the guesses would become more and more accurate. Some people became so sensitive that they could get it right every time!

The A and B states were, of course, states where the alpha or beta rhythms were present. How long do you think the sensitivity took to develop. Weeks? Months?
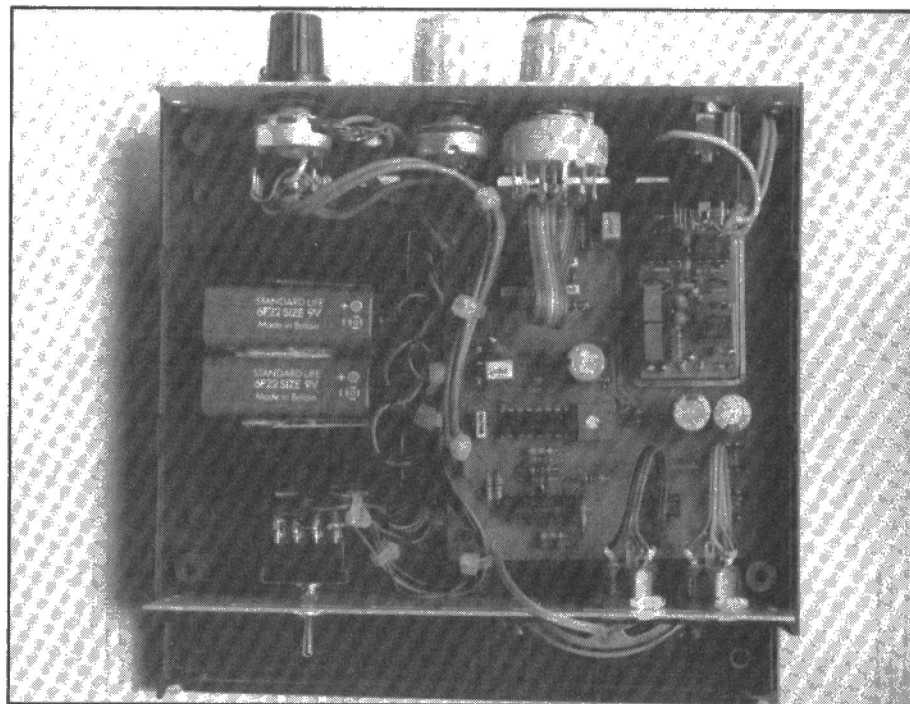
Not at all. After only three hours, most of his subjects were right 75 to 80 percent of the time!

Once Kamiya's subjects had learned to recognise the alpha and beta states, it was not long before they learned to stay in one state or the other. Concentrating on the alpha rhythm, he used a modified EEG machine which produced a tone whenever alpha activity was present (just like the ETI monitor). Eventually he taught people to produce alpha on command — one ring for stop and two for go!

Kamiya's first experiment has the disadvantage of requiring two people — a 'subject' and an 'experimenter' but with the monitor you can do it all yourself.

Set the controls to 'alpha' and 'integrate' and adjust the gain control until the sound just stops. Close your eyes and let the alpha rhythm come, just to check on the gain setting. If all is well, set the output switch to 'mute'. Now you have no clue from the monitor to tell you whether or not you're producing alpha.

Settle back in your chair and place the monitor so that you can flick the output switch without having to move more than a finger. Every time you feel particularly relaxed and your mind is not thinking of anything in particular, flick the output switch to 'integrate'. If you are producing alpha the monitor will sound, if you're not, it won't.

If you are training someone else, you can duplicate the experiment more precisely. It is a

simple matter to add a headphone socket to the monitor, and by listening to the sound while your trainee hears nothing you can take Kamiya's place as the experimenter. There's no need for a bell — this was used because the experimenter and subject were in different rooms to avoid any distractions.

When you have had reasonable success at guessing your alpha state, learning to control it should be easy. Often, this kind of training is done in less than an hour. How long you practice is determined only by the amount of control you want to achieve.

The first thing to try is to keep the alpha rhythm going for as long as possible. At first you will probably find that the slightest distraction will turn it off — even the sound from the monitor! You'll get a beep every five seconds or so but after a while you'll be able to keep the monitor sounding for longer and more frequently.

Having trained yourself to produce long trains of alpha, the final step is to increase the amplitude. Set the gain control lower and try to make the monitor sound. When you have succeeded in producing a five second burst of alpha, set the gain control a little lower still and try again. After the next five second burst, set the gain even lower, and so on.

Although it is possible to achieve a good level of control in a surprisingly short time, it's best not to push too hard. Three hour

long sessions are OK for research laboratories but not sensible or desirable at home. Take it easy and do one or two half-half sessions a day. Don't be too impatient. Even if it takes a week, it's not that long out of a whole lifetime, is it?

Dr. David Shapiro of the Harvard Medical School discovered an interesting way to speed up the learning process. Every time one of his (male) subjects built up a score of twenty correct responses, he would be rewarded with a five second flash of a Playboy nude! Shapiro's experiments were actually for blood pressure control rather than EEG but a similar principle no doubt applies. There's no record of how high his subject's blood pressure rose during the reward!

One thing that seems to emerge from many biofeedback studies is that learning proceeds faster if the feedback is given in an interesting way, possibly in the form of a game. Sterman used a projector to display a picture which was slowly completed as his subjects produced more of the appropriate type of brainwave. This could be duplicated quite easily with the aid of a home computer and the monitor's output sockets.

Dr. David Lewis chose an electric train set as the feedback from his EEG machine. The more alpha produced, the faster went the train! Dr. Lewis's work was the subject of a recent QED television documentary, so you may have seen this yourself.

Why Do It?

If you haven't built the monitor yet, you may be wondering why you should want to control your alpha rhythm in the first place. If you *have* built the monitor, you've got the answer already. It feels good!

The people who will get most benefit from alpha training are those under stress — which applies to an awful lot of us if the figures for stress-related illnesses are anything to go by. From my own experience I can say that it leaves you feeling calm, peaceful and clear-headed, which is a state I can highly recommended! Many other people report similar effects.

If feeling good seems too frivolous an objective, there have been numerous studies in relating alpha to some of its secondary effects — everything from pain

control to curing bruxism (excessive grinding of the teeth). The clinical application of alpha training is much too wide a subject to even begin on here, but at the end of the article I've suggested a book which gives an excellent overview of the topic.

One interesting line of research I would like to mention is Dr. David Lewis's 'Alpha Plan'. Dr. Lewis regards alpha not as an end in itself, but as a stepping stone to re-programming your mind. This is an almost unique departure since most clinical application of biofeedback has consisted, in essence, of finding people with some kind of problem, teaching them to produce alpha, and seeing if they get all better again. Sometimes it works well, sometimes not so well, and sometimes not at all.

The Alpha Plan takes the alpha state as a starting point and uses it to create a 'mind map' which sums up your current state of performance. Then the new 'program' is mentally rehearsed in alpha until it becomes something that *Must* happen. The whole procedure is almost on a production line basis, with forms and charts to fill in at all stages and scoring systems. (In learning to 'mind-mirror', for instance, you score six points for an experience 'as clear and vivid as if I had actually been there' and only two for a 'fleeting impression'). If it will do a tenth of what Dr. Lewis claims, it has to be worth a try!

Theta Control

The case for learning theta control works in both directions. Theta seems to be strongly associated with creative thought, so the aim of increasing it is to become a more imaginitive and creative person. On the other hand, it is also associated with drowsiness and research suggests that being able to *suppress* the theta rhythm will help you to cope with boring, repetive tasks without losing concentration. If you learn to control the rhythm, you should be able to do whichever you choose according to the circumstances.

Theta training can take place on two levels. At the borderline between waking and sleep, theta activity is at its most intense. If you start off at this 'deep' level, the aim is to maintain the state for as long as possible without drifting off into sleep or being too alert to your surroundings. If the creativity theory is correct, you

should find that just remaining in the state for long periods will give you new insight into your life or new ideas about your current projects and schemes.

One way to prevent yourself from falling asleep is to sit in a chair with no head rest (although it should be fairly comfortable). If you begin to nod off, the movement of your head will probably wake you up again. It also has the advantage that you won't disturb the electrodes. Turning up the volume on the monitor may also help to keep you awake.

'Twilight learning' is an interesting application of the theta state. Some of you may remember the fad for sleep learning of ten years or so ago. It soon fell from favour — mainly because it didn't actually work! Budzynski tried out a variation of this with a tape recorder triggered by theta waves so that learning would take place in the state of reverie before sleep. He had some success with the method and you can try it for yourself if you connect a tape recorder via the on-off output socket of the monitor.

Theta does not only occur close to sleep — some activity is present during the normal waking state. Theta training on the 'shallow' level can be used to increase your flashes of creative thought throughout the day and decreasing it may aid your concentration.

Further reading

An excellent guide to the current state of the art in biofeedback is 'Biofeedback — Potential and Limits' by Robert M. Stern and William J. Ray. In 1978 it was awarded the American Psychological Foundation's Media Award as an 'identification of what is fact, fantasy and fiction about biofeedback'. The authors write in a clear and interesting way (we might even consider them as contributors to ETI!) and the book covers the history of biofeedback, how to go about 'doing' it, how it can help with migraine, high blood pressure, asthma, and so on. It also contains an extensive bibliography for even further reading on all the topics it covers. Published by Bison Books, price £3.95.

Dr. David Lewis's Alpha Plan is detailed in his book called, naturally enough, 'The Alpha Plan'. Published by Methuen, price £2.50.

ETI

TECH TIPS
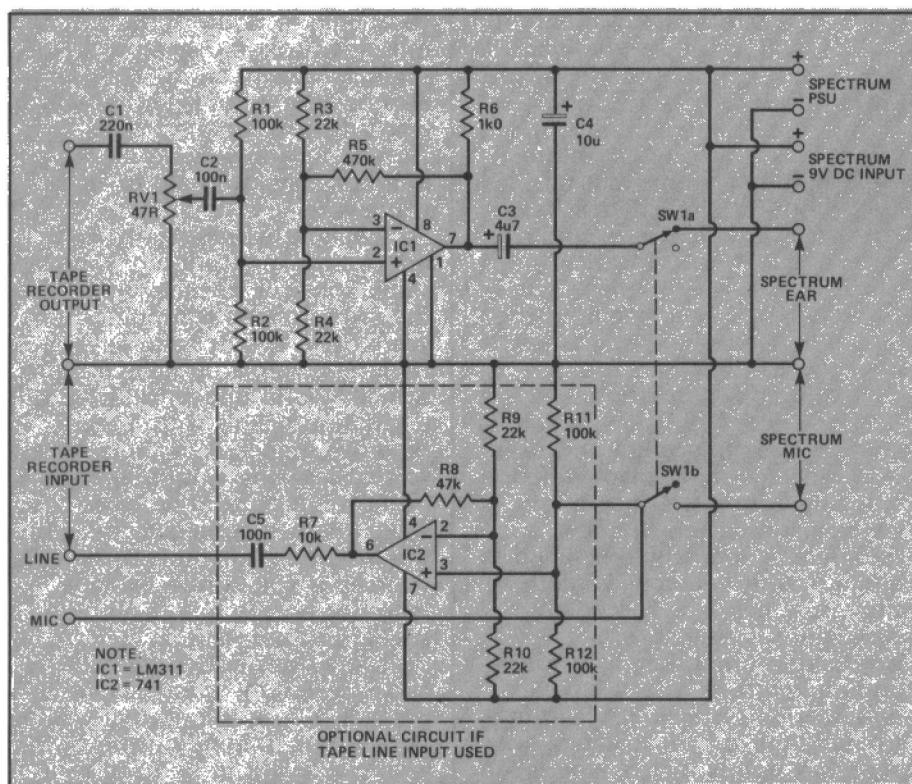
Tape Loader For The Spectrum

S.L. Jones
Anglesey

This circuit was designed to enable programs to be loaded into a Spectrum computer from the line output of a hi-fi tape recorder, thus avoiding the use of an extra portable tape recorder.

The low level output from a hi-fi tape recorder requires amplification to give a suitable level for driving the *ear* socket of the Spectrum. The signal also needs to be of a low impedance. If the microphone input of the tape recorder is used then this can be directly connected to the Spectrum *mic* output. However, if the line input is used this signal will also require amplification.

The output from the tape recorder is first passed through RV1 which acts as a volume control. The signal is then amplified approximately fifty times by IC1. A LM311 is used as it is capable of driving TTL loads. If the tape line input is used then the extra amplification can be provided by the optional circuit around IC2. SW1 is used to switch the connections to the *ear* and *mic* sockets of the Spectrum. This is necessary to prevent feedback when saving programs and saves having to plug and unplug the leads to the computer.

The power for the circuit can be provided from the Spectrum power supply. An extra lead is then required to connect it to the computer 9V socket.

For saving programs the mic output is selected by SW1 and the recorder level controls are set as required. For loading programs the ear input is selected and the signal level (RV1) is adjusted in a similar manner to the volume control on a portable tape recorder. It has been found that, in use, loading of programs is more reliable than with a portable tape recorder.

It may be possible to adapt this circuit for use with other computers.

Direct-Ion Improvement

A.P. Towner
London

Readers may be interested in some modifications made to the Direct-Ion air ioniser (ETI, July 1986). The author suggested having the neon lens on one end of the case with the bulb behind it. There is not enough room in the case to allow the bulb to fit inside the lens if it is mounted in this way. However, if the neon is soldered to the *back* of the PCB, the lens can be mounted on the top of the case with the neon bulb inside it, giving a brighter glow without having to fill the lens with Araldite (although you can still fill it with Araldite if you prefer the diffused light effect).

As suggested in the article, I used a PB22 rifle cleaning brush as the emitter, and mounted it as shown. The brush is threaded and will screw onto a 4BA bolt. After a few months of continuous use, the brush picks up a lot of dust and dirt and with this arrangement it can easily be removed for cleaning. The 4BA bolt also provides a useful connection point for EHT experiments, and for some of the outrageous activities suggested in the article! To improve the appearance, I surrounded the nut with the plastic ring from a 5mm LED clip.
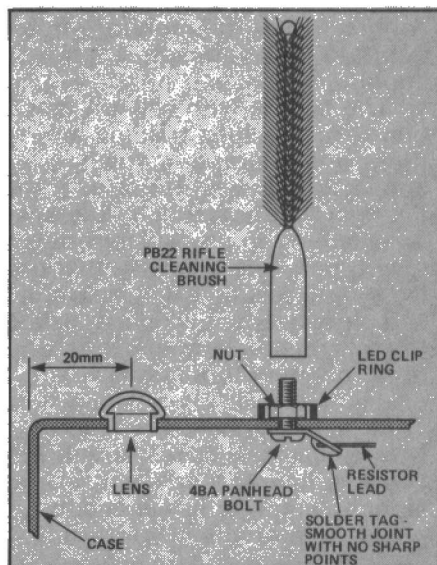
Variable Mark-to-Space Generator

L. Robinson
Aberdeen

This circuit produces a square wave output with a variable mark-to-space ratio selected by means of a rotary switch. The ratio can be adjusted between 9:1 and 1:9 in nine precise steps.

The 0 output of the 4017 decade counter is used to reset the NOR gate latch. One of the remaining nine outputs then sets the latch after the selected period. With the number 7 output selected as shown, the latch is reset after seven clock pulses have been received at the clock input, giving a mark:space ratio of 7:3.
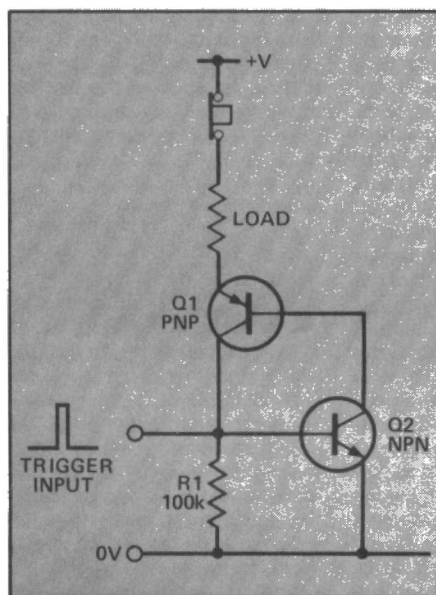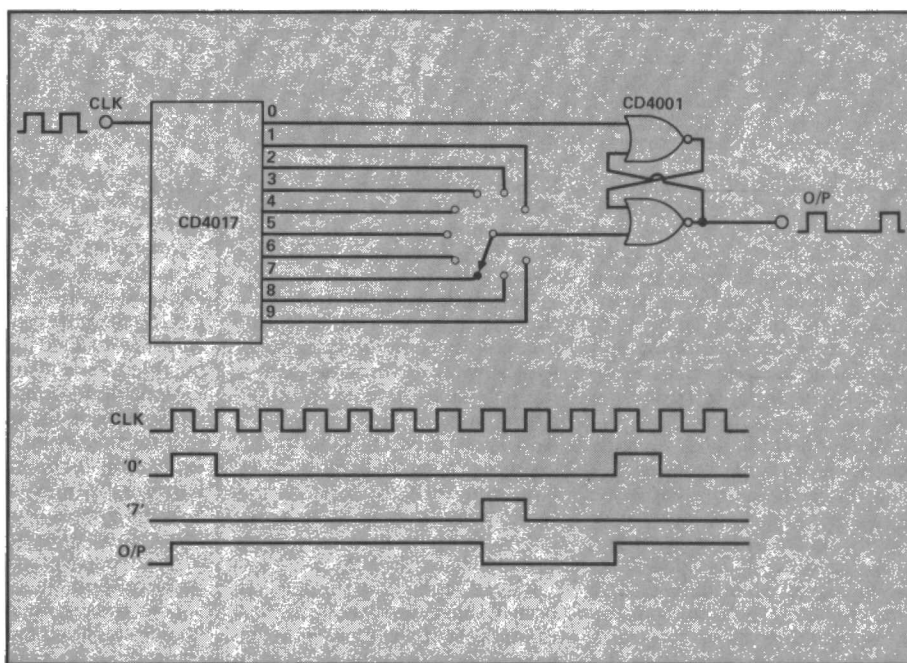
Two Transistor Latch

L. Robertson
Aberdeen

This circuit operates in a similar way to an SCR. When the trigger input is held high Q2 is turned on and, in turn, this turns on Q1. The collector current of Q1 provides the base current of Q2, developing a voltage drop of 0.7V across R1.

When the trigger voltage is removed the transistors will remain on because of this base current. The only way to reset the circuit is by removing the supply momentarily by means of the RESET pushbutton switch.

VDU Sync Sorter

L. Sage
Bingley

The circuit will accept either positive or negative sync pulses, and either composite or separate line and field sync, at TTL or CMOS levels. It produces a negative-going composite sync output. This greatly enhances the versatility of a monitor allowing it to be connected to a wide variety of different signal sources without the need to fiddle with sync switching.

This is particularly useful for schools and colleges where the person setting up or operating the video equipment may not be technical and just expect the various pieces of equipment to work without adjustment when connected up.

Separate line and field sync pulses are fed to Q1 via the two diodes. These isolate the pulse sources ensuring they cannot interact with each other. Q1 is connected as a phase splitter and together with the bias at the base D1,2 set the sync slicing level at around 2.7V. Opposite polarity sync pulses appear at the collector and emitter of Q1. Q2, 3 are biased off.

Positive sync causes Q2 to conduct resulting in negative sync output. With negative sync input Q3 (connected to Q1's collector) receives positive sync, again resulting in negative sync from the collector. The output is always negative-going regardless of the polarity of the input.

An input level greater than 1.7V peak will be accepted, the diodes slicing off any input greater than around 3V. R6 ensures Q2, 3 do not saturate and can operate at high speed.

The unit can be built into a monitor itself and the prototype was built into a TV converted to a monitor. If a composite sync is available (as with many home computers) then this is simply fed into one of the diodes, the other remaining open circuit.
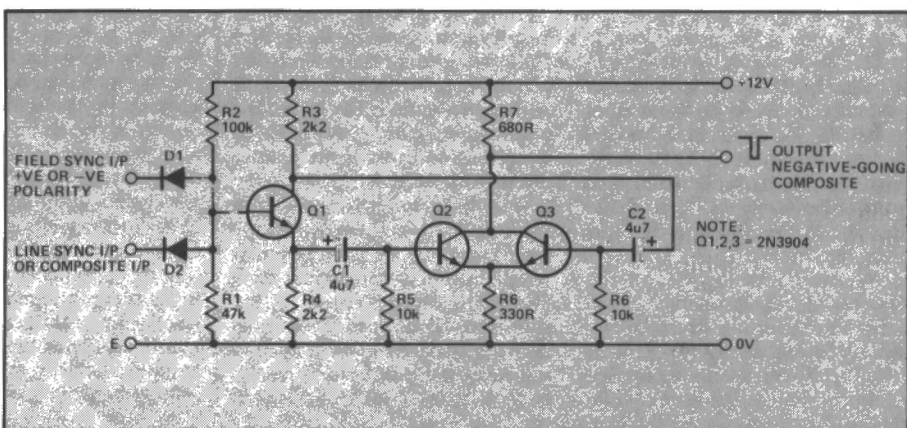
OPEN CHANNEL

Shock, Horror: Sun-spots Prevent Telecommunications! Ain't life strange? Here I sit on a wonderful sunny Sunday afternoon, high on a cliff-top camping site in North Yorkshire, overlooking the incoming tide, with the sounds of cattle lowing and sheep baah-ing in the fields close by and bees buzzing around the clover.

With us and two other caravans on the site it's hardly crowded. I've just packed away the barbeque (sausages and beefburgers for Sunday lunch) and the missus has just dozed off in her deckchair. She'll be mad when she wakes up and realises she's missed the Eastenders repeats on the telly.

With a start I realise that the price of this holiday is that I can't doze off too because there's work to be done. Although a writer's lifestyle is generally pretty advantageous there are times when work gets in the way and this month's Open Channel proves to be one of them.

It would be nice to say that I step into the caravan, pull out my word processor from its hidden flap to type in my tome, connect my cellular phone to the word processor and call the ETI office, connecting via the ETI auto-answer modem to download the article.

It would be nice to say that, but I can't. The site hasn't got mains supply facilities so my word processor can't be used (I can't afford a battery-powered portable). I haven't got a cellular phone (I *can* afford one but refuse to have one on the grounds that the phone interrupts my life enough when I'm at my desk, without doing so when I'm driving or when I'm on holiday) and I didn't bring my word processor anyway.

ETI hasn't got an auto-answer modem capable of downloading magazine copy, so my word pro cessor, cellular phone and modem wouldn't be of much use anyway.

Better By 1st Class Design

Instead, all I have is a pencil, an A4 pad and an old portable typewriter. After a rough first draft on paper, I shall bash out the article on the typewriter and post it with a first-class stamp in the village post-box later today on our evening stroll.

Even with the vagaries of the Royal Mail first-class service it will land on the Editor's desk no later than Wednesday.

Oh sure, with a lap-top portable computer, modems and cellular

phone it could have been received one or two days sooner. I'm not disagreeing with that. But all that costs a lot of money — a first class stamp costs 18p.

The whole point I'm making is that anything is possible with modern-day communications systems — we all can use them to give the great advantage of speed.

On the other hand, unless that extra speed is vital (which I would venture to suggest, in most cases, it is not) then the cost of the telecommunications systems probably makes the whole thing economically unviable.

It's not that I'm a Luddite. Far from it, I am always among the first to welcome change for the better when it's instigated by electronics developments. What I do disagree with, however, is change for change's sake — which seems to occur far too regularly, these days.

In industrial marketing and sales terms, companies must be 'market-led' — the products which the company offers for sale must be those wanted by the customers, *at a price the customer is prepared to pay.*

New Heights

A recent report on 1985-86 growth of world semiconductor companies shows that most Japanese companies must have it right. Sony, the fastest expanding company in the world almost doubled in size. Even the slowest growing Japanese company, Hitachi, increased by about a third. In contrast the fastest growing European semiconductor company, Philips, grew by only 26% or so.

New Heights II

From the spring of 1988, a small number of British Airways transatlantic Jumbo jets will be fitted with on-board telephones for passenger use, on a preliminary trial basis.

Outgoing calls will be possible, linked via an Inmarsat satellite and Goonhilly ground station into BT's telephone network. One wonders, is this an example of market-led philosophy. Brings down to earth my objection to having a cellular phone, doesn't it?

Now, back to my holiday. The sun is still shining, Eastenders is long over, the missus has just woken up and the tide is in. I think I'll take a wander down to the shore to do a spot of fishing. Perhaps I'll catch some supper — red herring no doubt.

Keith Brindley

PLAYBACK

When I consider attempts to produce radical improvements in sound quality I am reminded of the story of the man who lost a marble. He searched high and low in well lit places but not in dark corners. When asked why, he explained that he wouldn't be able to see it in the dark.

Arguably, the loudspeaker is the weakest link in the audio chain, so there would seem little point in expending money and effort to improve the quality of the rest of a sound system until good loudspeakers have been installed even if other parts of the system are easier to find.

Compare two different but good quality amplifiers and then do the same for two sets of loudspeakers. The difference between the amplifiers will hardly be detectable while the loudspeakers will usually sound very dissimilar. At least one pair of speakers must be giving inaccurate reproduction.

Let's assume that the ideal loudspeaker should give an accurate acoustic replica of the electrical signal from the amplifier. There are several good technical reasons why most loudspeakers cannot. First of all, the force applied to the loudspeaker cone by the coil is proportional to the strength of the magnetic field. It is almost impossible to avoid small variations of field strength along the gap between the pole pieces. As the coil moves, it experiences different magnetic fields and hence responds differently.

The cone of the loudspeaker must be suspended (or it will fall out!) and the suspension itself adds distortion. There must obviously be a restoring force tending to centre the coil in the magnetic gap or else there is nothing to stop it gradually drifting to one end or the other. This restoring force inevitably compresses the peaks and troughs of the waveform.

Even if the magnetic field and cone suspension were perfect, the speaker is mounted in a box. As the cone moves back into the box, the air inside is compressed which resists further motion. If it moves outwards, the air inside is rarified, with the same effect. This also compresses the tips of the waveform. Internal box resonances increase the effect at some frequencies and reduce it at others. Ported enclosures reduce this problem and maintain the low frequency response down to a cutoff frequency, below which the response tails off very rapidly. The infinite baffle (closed box) design

starts to lose low frequency response from a higher frequency but the rolloff is gentler.

Lack of rigidity in the box adds its own 'colouration' (distortion) to the sound as well.

The frequency response of a loudspeaker would not be flat even if it were perfectly linear. The coil has both inductance and resistance, and therefore does not work with the same efficiency at all frequencies.

Mechanical resonance due to the mass of the cone allied with the suspension and box pressure effects also adds peaks and dips to the graph of the frequency response. This is reduced to some extent by the back EMF generated by the loudspeaker coil as it moves which opposes the motion — if the amplifier's output impedance is low enough not to resist this. Even so, the self resistance of the loudspeaker coil limits the effectiveness of this damping no matter how low the output impedance of the amp or how thick the loudspeaker cable.

Audiophile CD

Sony has introduced a new top end compact disc player, the CDP-555ESD which will give you 5p change out of a cool grand. The design advantages claimed should satisfy the testiest hi-fi tester if they work out in practice. In particular, the analogue power supply is separate from the digital one to avoid low level digital noise on the sound and the left and right channels are completely isolated to give the best possible channel separation.

Sony also claims the use of non-inductive electrolytic capacitors and plastic moulded carbon film resistors with gold plated end caps. Surprising, as I understood current thinking to favour metal film resistors for hi-fi.

One aspect which I hadn't thought of before I saw it on Sony's press release is that the digital output is synchronously latched to avoid any traces of jitter on the samples, which I suppose might cause intermodulation.

Sony says this model replaces a two box player costing much more but the bits which must be kept separate have been separated while fitting them all in one case. Now we can all afford one!

BOOK LOOK
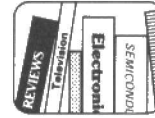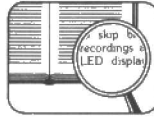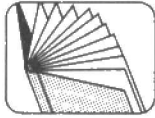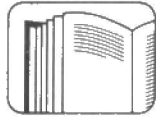
This month I'm taking a look at a couple of books for readers in their second childhood. There are many people who think that adults playing with train sets is a display of immaturity (my wife for one). Now you and I know that great fulfillment can be had at the controls of an electric train!

Whether you play trains for your own benefit or it's your kids who spend the time on the tracks, these two books will help you get that little bit extra out of the train set with the help of a little electronics and a home computer.

Electronic Circuits for the Computer Control of Model Railways by R. A. Penfold (Babani) £2.95.

Yet another work from the ubiquitous Mr. Penfold.

The circuits are nominally aimed at owners of the BBC micro although it is only the 8-bit user port which is used so other machines are equally applicable.

The book is divided into two sections of power control and position sensing — the two main ingredients of model train control.

The power control section starts with a simple relay driver and works through a ramping controller, a digital to analogue converter and various smoothed power supplies to a pulse width modulated control.

Unlike most of the Babani books, this one does have some constructional details for the circuits, but only for a couple of them. A PCB foil and overlay is provided.

The ramping controller is not the most exciting circuit in this section so it is rather strange to find this one singled out for the full treatment. However, anything's better than nothing.

The second half provides two simple optical detectors (broken beam and 'shadow detector') and a magnetic reed switch sensor. These are not new, of course, and can probably be found in innumerable other Penfold/Babani books.

The shadow detector (a light threshold switch meant to be placed pointing upwards between the tracks so a passing train casts a shadow on it) is given the full construction treatment with a PCB foil and overlay. However, as the circuit is one chip and two transistors, any method not using stripboard has to be overkill.

The second section also has a few miscellaneous circuits thrown in for good measure — an LED signal lights driver and a points controller.

For hardened fans of the Babani genre this book should please well. It raises no eyebrows and covers next to no new ground. There's little practical help either and absolutely zero software backup. It is cheap, though.

Computer Projects for Railway Modellers by Roger Amos and Martin Cock (Patrick Stephens) £4.99.

When the title talks about 'railway modellers' and not trains sets or toy trains, you know you're into the serious stuff.

Regular ETI readers may remember Roger Amos' columns in this mag around a year ago.

This book is aimed at Beeb and Spectrum owners and includes many program listings to use the hardware. Of course much of what it says can be applied to other machines too but your own software will have to be written for that.

This book is far less specific about particular arrangements of circuits than Penfold's but it is also more in line with the accepted ideas of 'railway modellers'.

It concentrates on the normal method of train control of splitting the layout into sections and switching each section under the control of the main controller as a train passes onto it. The circuits given are for the computer control of the switching, involving both train detection (by monitoring the track section's conductivity) and power control (relays and ADC methods).

Some straight computer programs requiring no hardware at all are also listed — a timetable display and sound effect generator, for example.

No details of construction of the circuits are given. This is particularly strange (and rather a shame) as so much other basic explanation is given.

It's obvious this book was written by train enthusiasts dabbling in computers and electronics, whereas Mr. Penfold is an electronics enthusiast venturing into the realm of train sets.

Nevertheless, both books can serve a useful purpose. Penfold's is better for the mere enthusiast. It gives plenty of scope for experimentation with both electronics and trains. The book from Amos and Cock is far more for the dedicated train enthusiast who wants to get his layout that bit more up to date.

Malcolm Brown

KEYNOTES
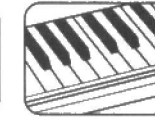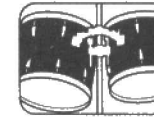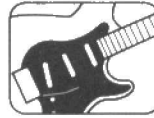
The utopian goal of a music creation/editing system based entirely on software running on a personal computer is still a long way off. The gist of computer music is to *replace* hardware with software, rather than to augment existing hardware.

The excellent software packages now available for MIDI sequencing, sample editing and synth parameter editing do not constitute computer music, strictly speaking, since they do nothing to reduce the cost of a set-up, while versatility and upgradeability remain limited mainly by the hardware itself.

Open Options

The ideal is to perform all synthesis and processing in software, which is by its very nature open-ended and non-restrictive. Hardware should take the form of a personal computer equipped with no more than a keyboard interface and an ADC and DAC convertor or two or a serial digital link to, say, an R-DAT recorder.

Given that interactiveness and thus instantaneous response (real-time operation) are what music and musical instruments are all about, the current generation of microprocessors and hence personal computers are quite simply too slow to turn the computer music dream into reality at present. Real-time computer music is actually a reality at establishments such as Stanford University and IRCAM but only at the expense of resorting to VAX 11/780 mainframes supplemented by floating-point array coprocessors, pressurized fuel tanks, wide wheels, you name it.

Most of us will have to contend with varying degrees of compromise for the time-being.

Music For Desktops

One such degree of compromise is being offered by the CDP. This is not a new political party but an acronym for the Composer's Desktop Project, which is closely associated with the electronic music studio of York University. What they have done, or are still in the process of doing, is to port the impressive CARL audio software (mentioned last month) to the Atari 1040ST. The CARL programs are designed to run under a full-blown UNIX operating system which would seem to make the choice of the non-UNIX Atari

not only ambitious but even unwise, in light of the spirally-decreasing cost of true UNIX workstations.

Non-real-time audio processing requires some form of temporary bulk memory for storing sound sample data prior to playback. This means a hard disk, with about 1Mb of capacity for every 11 seconds of required sound. York ran into another problem here — the Atari's built-in hard disk interface is unsuitable for the fast transfer of data from disk to an output interface at playback time and so it was found necessary to add an extra SCSI-standard board to achieve this.

The output interface itself is not of the ADC, DAC variety but instead a serial EIAJ-format link to a Sony PCM adaptor which contains the necessary convertors, also allowing digital recording on a Betamax video recorder.

The PCM unit requires the surgical implant of a small PCB and DIN socket in order to gain access to the convertors. Total cost of the CDP system with a 40MB hard drive is over £3,500 (not including Betamax).

Quick, Quick, Slow

At the March launch of the CDP at London's Royal College of Music a duophonic jingle lasting about two seconds took four minutes and 22 seconds to generate.

CDP promised the future availability of a 68881 maths coprocessor for the Atari, an unworthy vessel if ever there was one since the machine makes no provision for such a thing. CDP fully recognized, however, that the main priority was to get the software fully running first. It still isn't and development of the 68881 board, which should increase throughput by a factor of up to ten, is now scheduled to commence next year.

A paper presented by two members of the project at the London AES conference, the week before the launch, claimed 'The large gap between what is possible theoretically and technically and what is affordable and practically useable by the individual composer is one which the Composer's Desktop Project aims not to fill, but rather to short-circuit.'

If the CDP get their act together before the next election then they stand to win some votes but in the meantime there are alternatives to consider.

Bruno Hewitt

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E8305-5	Balanced Input Preamplifier	F
E8307-2	Flash Trigger-sound or FR	F
E8308-1	Graphic Equaliser ⅓ Oct/Chnl	M
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E8406-3	Audio Design RIAA Stage	G
E8406-4	AD Buffer/Filter/Tone	H
E8406-5	AD Headphone Amp	F
E8406-6	AD Preamp PSU	K
E8406-7	AD Power Amp	H
E8406-8	AD Power Amp PSU	J
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OOPS!

FM Stereo Tuner (February-April 1987)
In the parts list on page 49 of the February issue, C2 and C3 are listed as 270n types. This line should refer to C2 and C23 and the value should be 470n. In Fig. 7 the un-labelled PCB pad in the top right-hand corner is the +15V input from the power supply. In Fig. 1 in the April issue there is an un-labelled arrow leading from the top of the diagram. It should be marked CONTROL VOLTAGE OUTPUT TO MUTING CIRCUIT. The arrow to the right of the un-labelled one is marked '+5V IN' and should read '+15V IN' In Fig. 6 in the April issue, C63 and C64 should be shown as 330p, not 3300p.

Power Meter (May 1987)
The foil for the budget power meter was given 50% full size on the foil pages. The correct size foil appeared in the June issue.

MIDI Master Keyboard (June 1987)
The foils for the CPU board were given 64% full size on the foil pages. Photocopies of the correct size foils can be obtained by sending a SAE to the Editorial address.

Flat Alarm (June 1987)
In the circuit diagram Q2 is shown as an NPN transistor. It should be a PNP device as given in the parts list. IC4 is given in Fig. 2 as a 74LS260 and C5 as 470n. They should be 74LS132 and 4µ7 as in the parts list. R13 is incorrectly given as 280R in the parts list instead of 270R.

Nuclear Strategy Simulator (July 1987)
The bridge rectifier (BR1) on the overlay diagram has no polarity markings. It should be positioned with the positive at bottom left, connected to the track which connects to IC8 IN and C4 positive.

Telephone Alarm (July 1987)
In the component overlay (Fig. 2) ICI and IC2 should be swapped. In addition the capacitor to the right of ICI,2 is C1 and the inductor between them is L1. The unmarked resistor to the left of L1 should be a wire link.

Kappellmeisters (July 1987)
The position of the speaker port in the front panel was omitted from Fig.2. This should be a 7¼x4½in ellipse centred across the panel with its top edge 2½in below the panel top.

Knight Raider (August 1987)
In Fig.1(a) pins 4 and 5 of ICI are swapped. IC2-3 show the correct pin-out.

Car Alarm (August 1987)
In Fig. 1 Q7 is not numbered and its emitter is shown unconnected. This connects to earth. The transistors in the parts list went a little awry. Q2-6 are BC237 and Q7 is a TIP31.
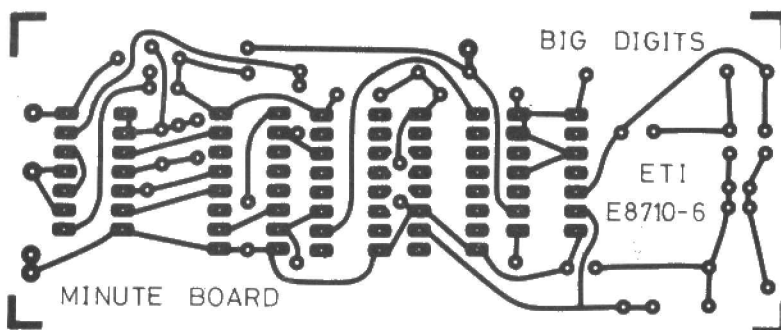
Boiler Controller (September 1987)
In Fig. 2 (a) the primary of T2 is shown connected to Earth. This should be neutral. In Fig. 2(b) one of the bridge rectifier diodes, D6-9, is shown the wrong way around. This is correctly shown in Fig. 5.
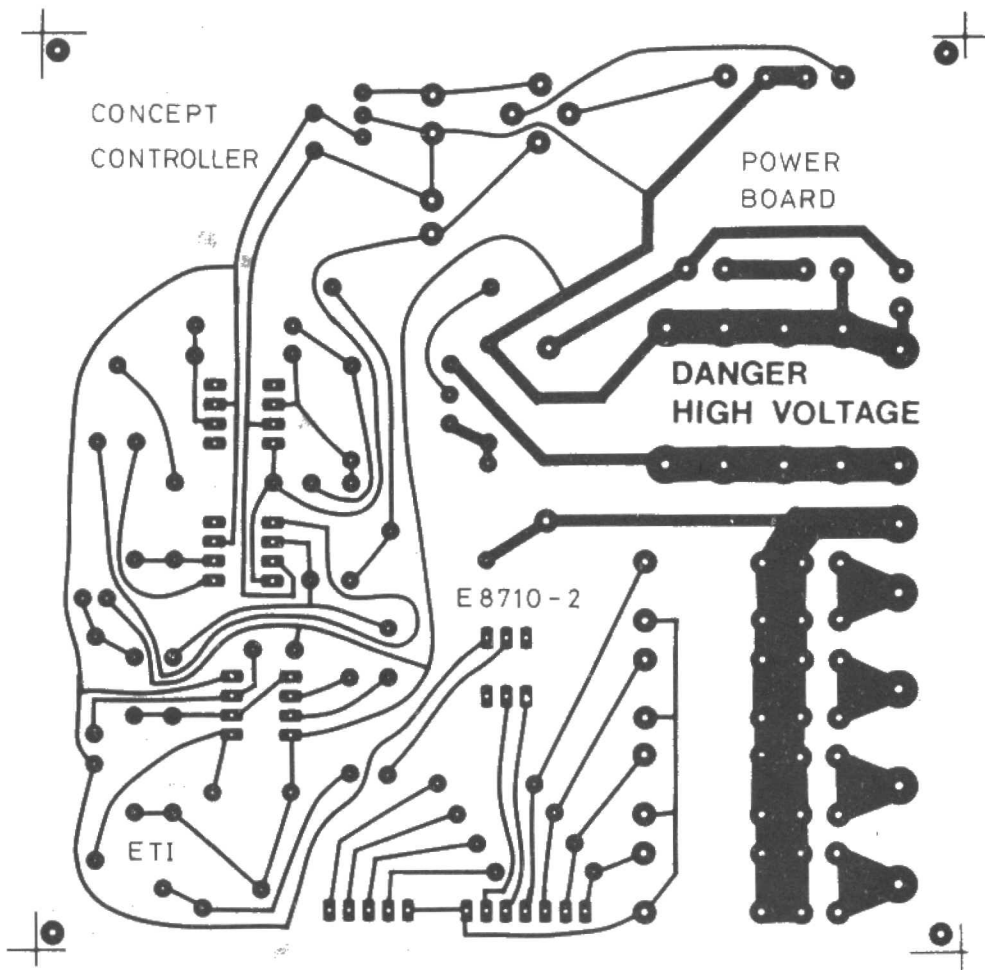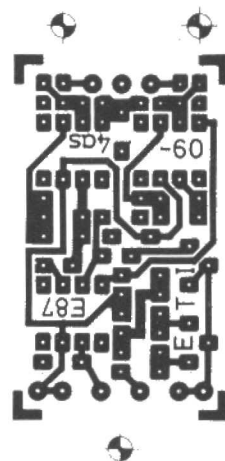
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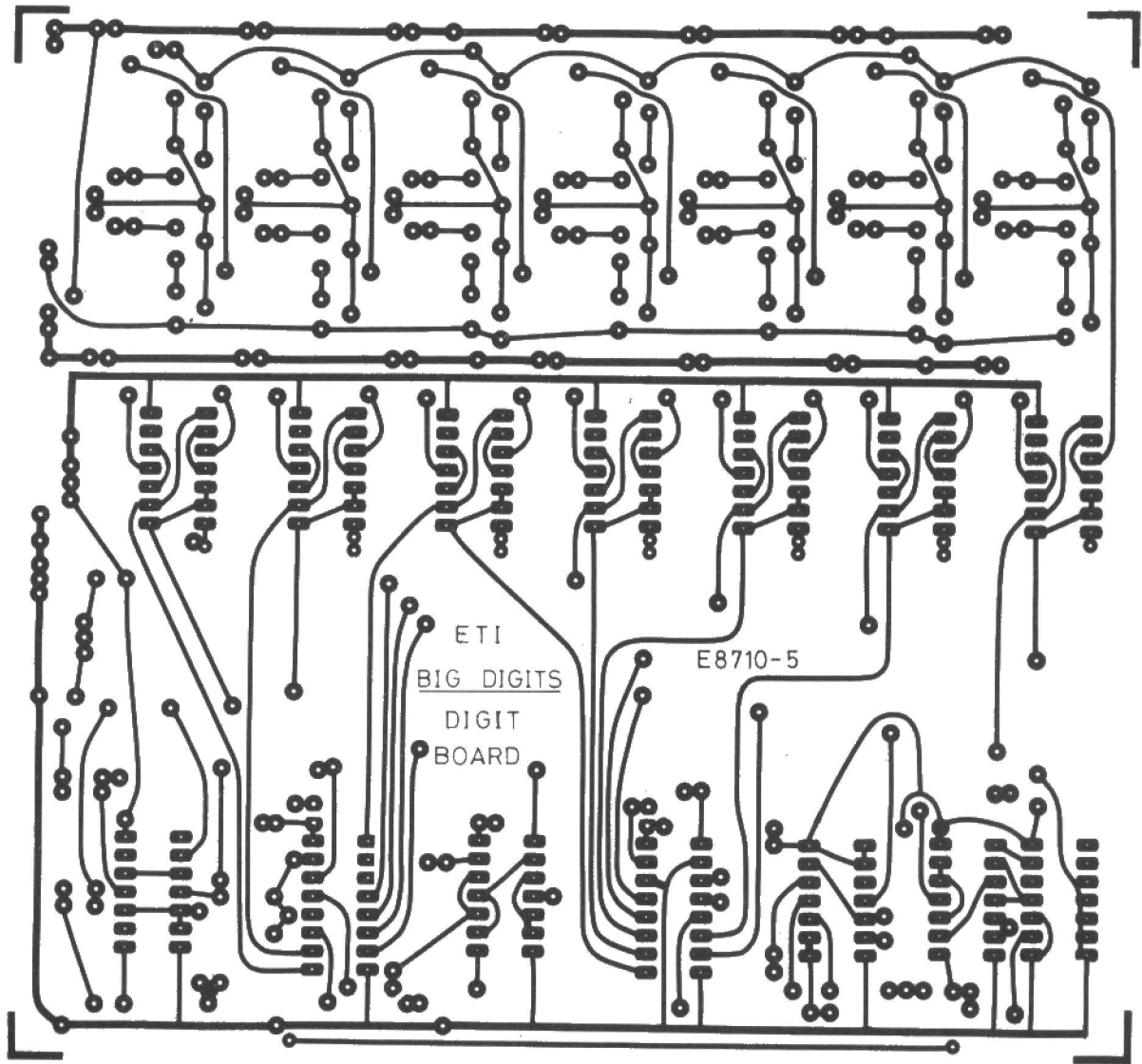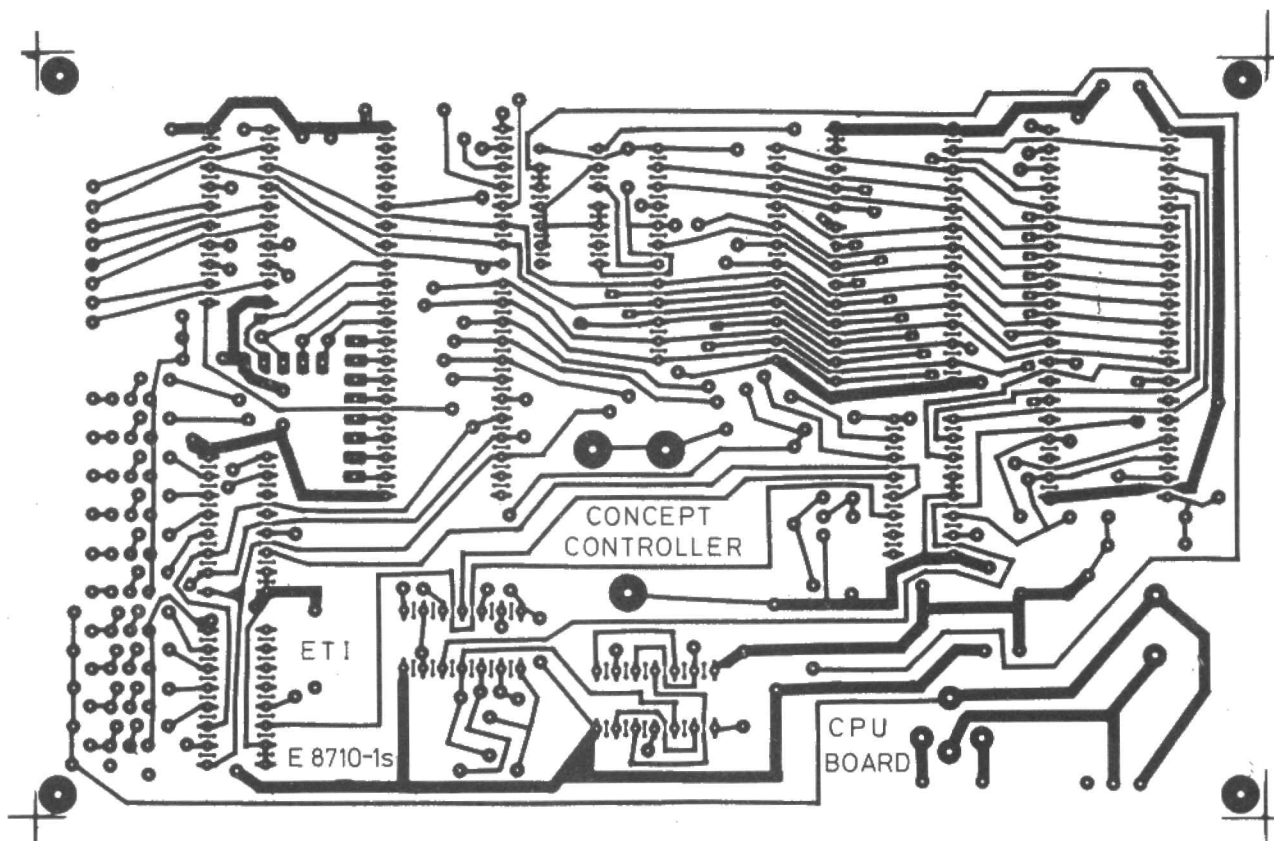
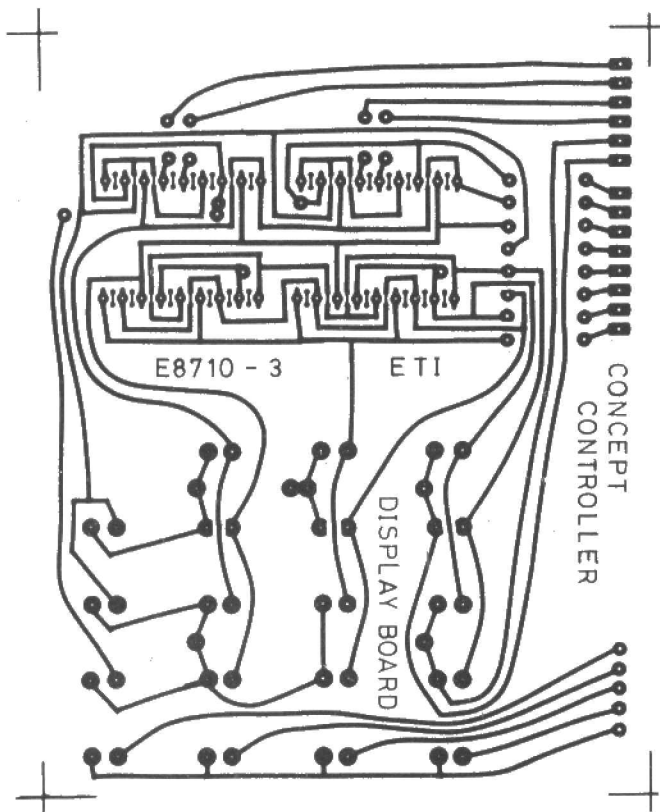The Big Digits digit board.
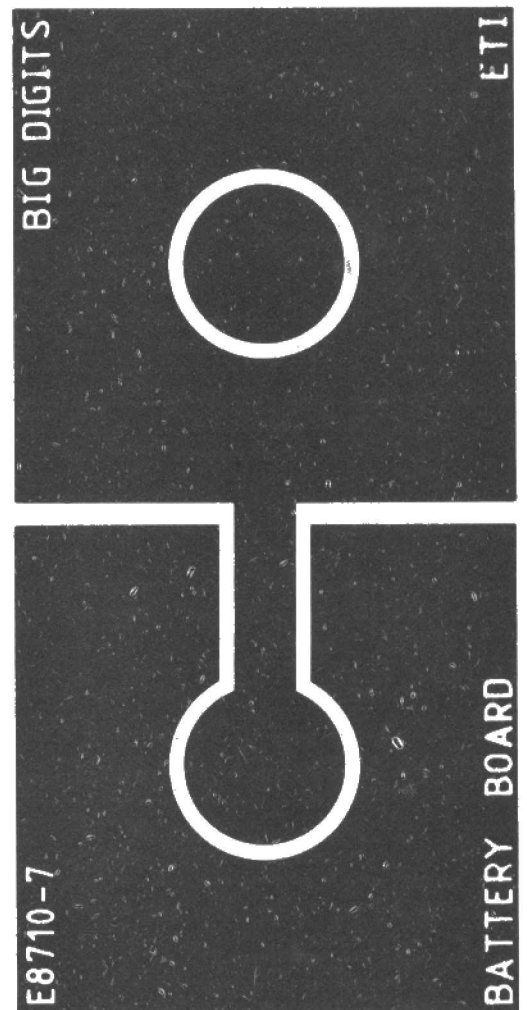
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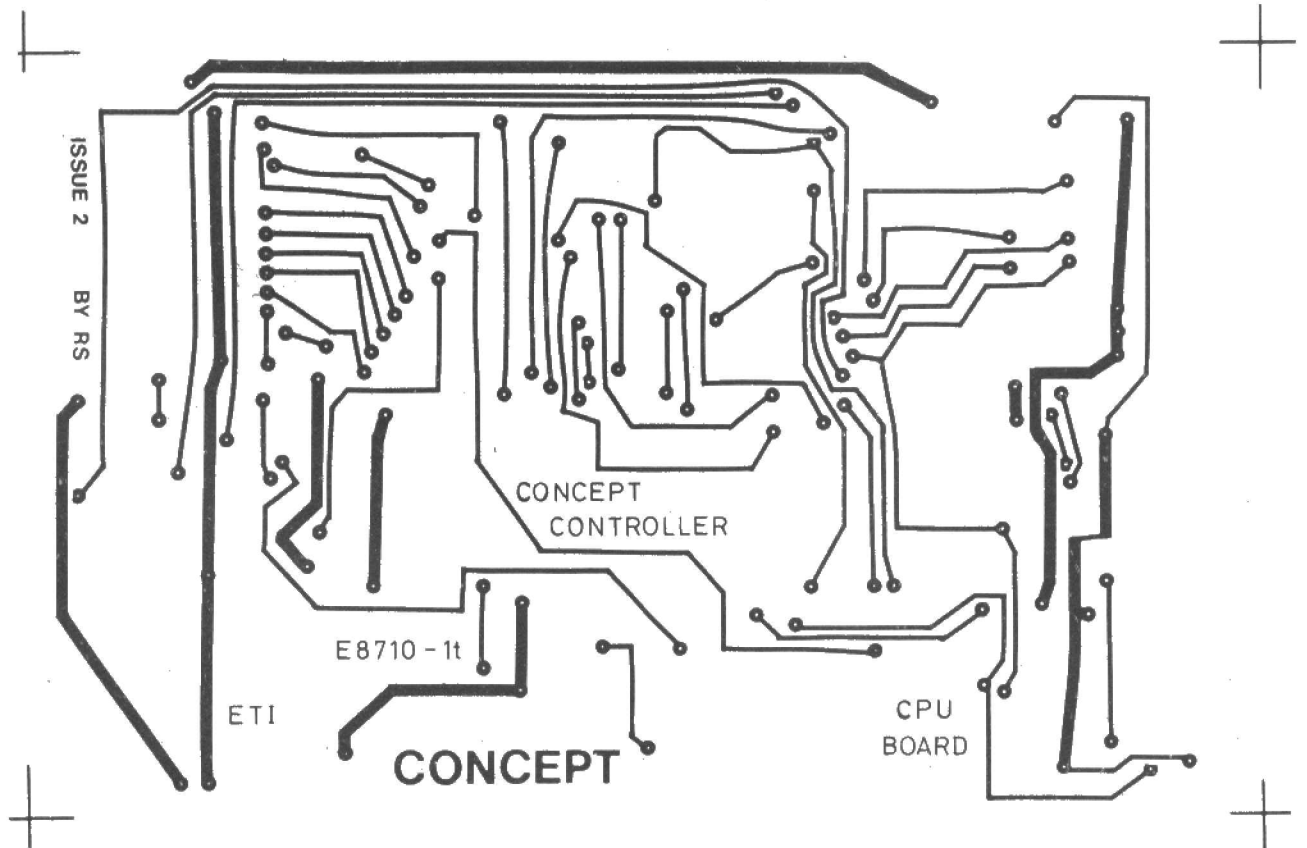
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ENTERPRISE 64 TECHNICAL MANUAL WANTED: Will buy manual or photocopies. Contact Niall Keegan, 63 Carysfort Downs, Stillorgan, Co. Dublin, Ireland.

WANTED: Complete set of ETI from first to latest. Please telephone Gordon: (0945) 589867.

WANTED: Circuit diagram of 6 volt digital speedo for bicycle, 26in wheel. LED/LCD. Postage refunded. P. Collins, 20 Hinton Street, Splott, CF2 2EU.

WANTED: BURGLAR ALARM. Cost plus airmail package, to J. Samuel, PO Box 11295, Windhoek 9000, South West Africa.

MICROBOX 2 complete and working, also Dennis system with high-res video card. R. Allen, South View, Forncett-End, Norwich. Tel: (095389) 420.

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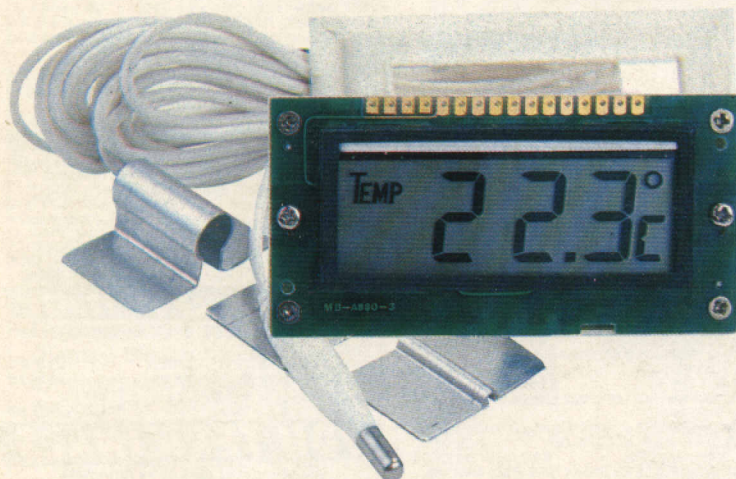
Temperature Module
Versatile thermometer module displays in °C or °F, includes a 12 hour clock and serial data output. Temperature range −5°C to 50°C (internal), −20°C to 70°C with external probe. Overall size 68 x 35 x 23mm deep. Probe (max. length 3m) and bezel also available.
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